UV Spectral Stability as it Relates to the UV-Bulb Temperature

By Jim Borsuk and David Armitage

The art of bulb manufacturing. Technicians ensure precision-manufactured bulbs of the highest quality standard expected in the UV curing industry.

For optimum ultraviolet (UV)-curing efficiency, the material to be cured must match the specific spectral output of a UV bulb. This output, measured in nanometers at each wavelength throughout the UV range, is the defined spectral measurement used to quantify one UV-bulb type from another. Each bulb has its own unique characteristic (or footprint) that separates one type of bulb from another. The chemical composition within the bulb gives the type of bulb its unique spectrum. In the UV-curing process, each bulb is classified by the output in each UV spectral range—identified as UVA, UVB, UVC or UVV.

UV-curable materials utilize photoinitiators which are formulated to react to energy from specific wavelengths of UV light. The UV energy provides the ability for cross-linking, thus changing any liquid or paste to a semi-solid or solid form. Matching the photoinitiator wavelength to the specific wavelength of the UV bulb will help assure a proper cure for the ink, coating or adhesive.

This match is paramount to proper curing. Matching the bulb output to the material's curing characteristics will help to assure a successful cure. Factors such as UV-material formulation, coating thickness and process speed play an important role in selecting the correct UV-curing system. Once the equipment is selected, the bulb type is matched to the material requirements for proper material cure.

The UV-spectral wavelength is the most important consideration when selecting a UV bulb. Any change from this material/bulb match will significantly affect the process cure.

Spectral Output of UV Bulbs

UV bulbs emit UV light through the plasma created in the bulb envelope. The UV-spectral output range is considered to be from 100 to 460 nm (nanometers). Figures 1-6 on the following pages display the different UV-spectral outputs. Each bulb used for UV curing displays a unique output that utilizes a specific part of this range. The ranges are identified as UVC (short wavelength 200-280 nm), UVB (short-medium wavelength 280-320 nm), UVA (medium wavelength range 320-390 nm) and the UVV (long wavelength 390-460 nm). UVV should not be confused with VUV (vacuum UV 100-200 nm), which does not transmit in air and is, therefore, not referred to when discussing the UV output of bulbs. Specific ranges are matched to the curing requirements of material coatings.

Mercury is the main UV-bulb fill ingredient and it helps to create a specific spectral output. When the bulb is energized, the mercury vaporizes and is carried into the plasma, giving considerable output in the UV range. Mercury bulbs have a unique spectrum consisting of a short wavelength

Figure 1

Mercury bulb spectral output

One of the most commonly used lamps and frequently referred to as the "H" bulb; this lamp delivers a good broadband output across all wavelengths.

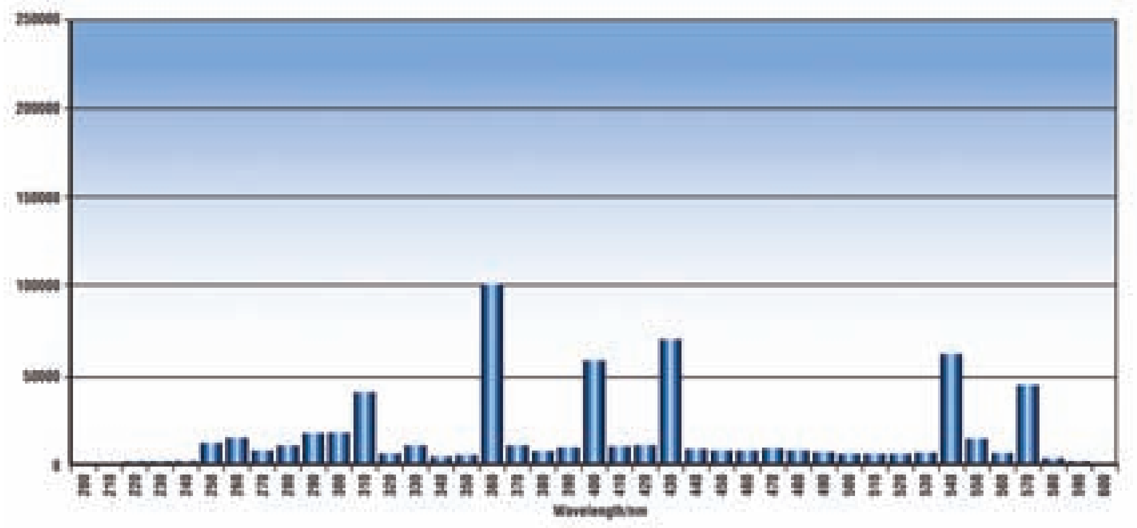


Figure 2

Iron bulb spectral output

Frequently referred to as the "D" bulb, this lamp is rich in UVA output.

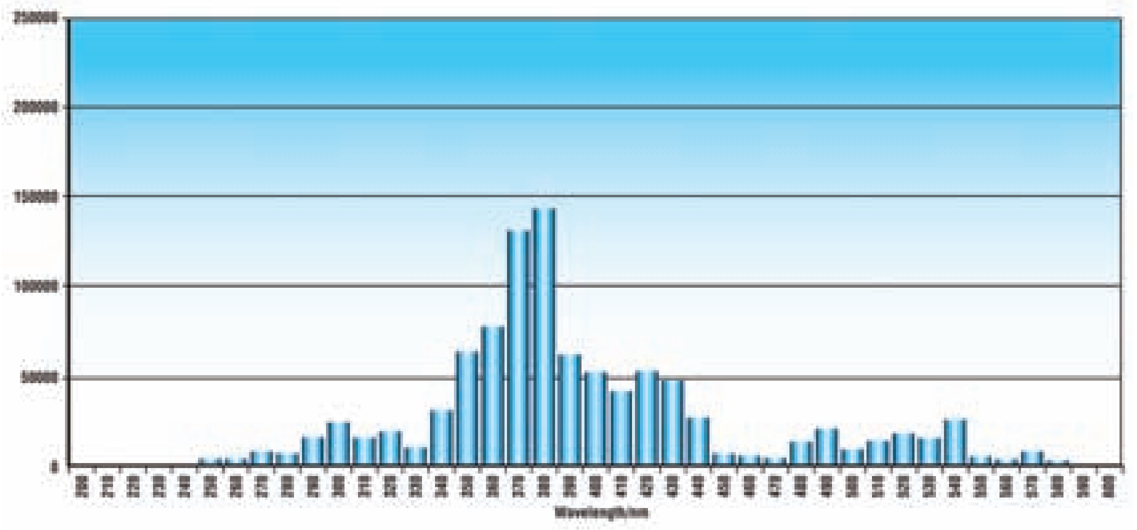


FIGURE 3

Gallium bulb spectral output

Frequently referred to as the “V” bulb, it is a strong performer in the UVV range. This lamp delivers excellent output in the 405 nm to 420 nm wavelength.

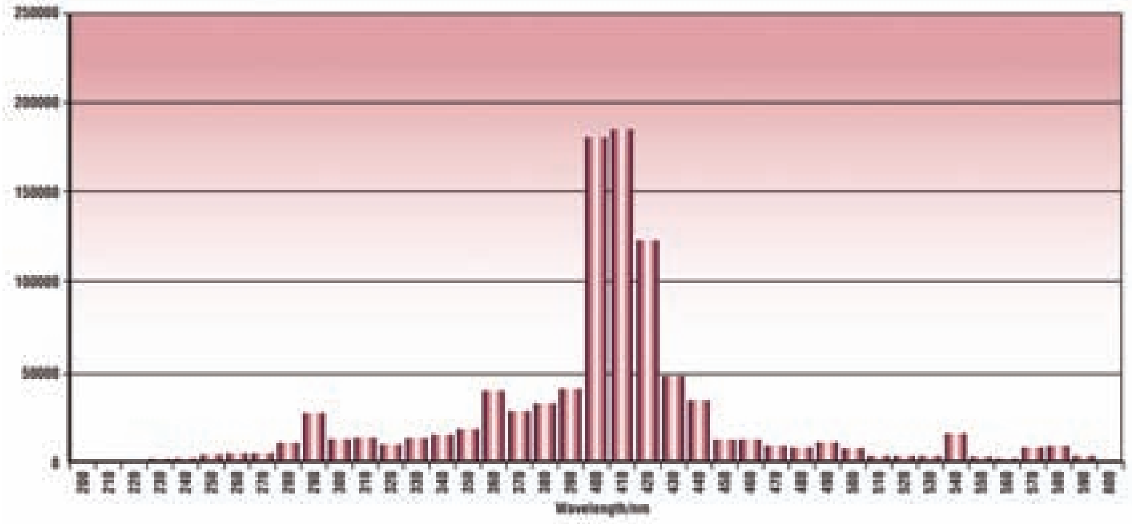


FIGURE 4

Indium bulb spectral output

Frequently referred to as the “Q” bulb, it is a strong performer in the UVV wavelengths up to 450 nm.

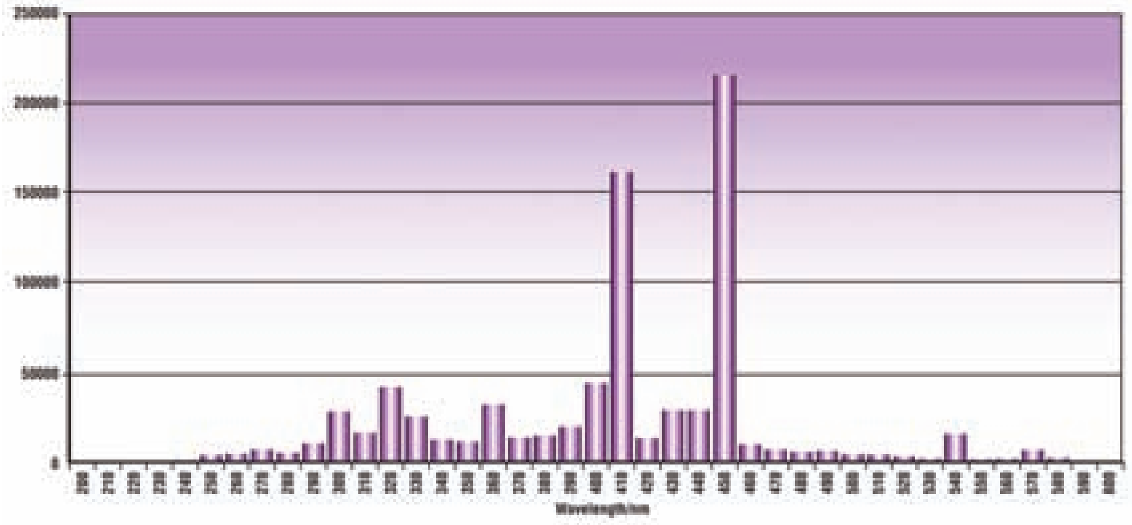


FIGURE 5

Mercury+ bulb spectral output

Frequently referred to as the "H+" bulb, this lamp is similar in output to the mercury bulb, but with enhanced emissions in the shorter UVC wavelength.

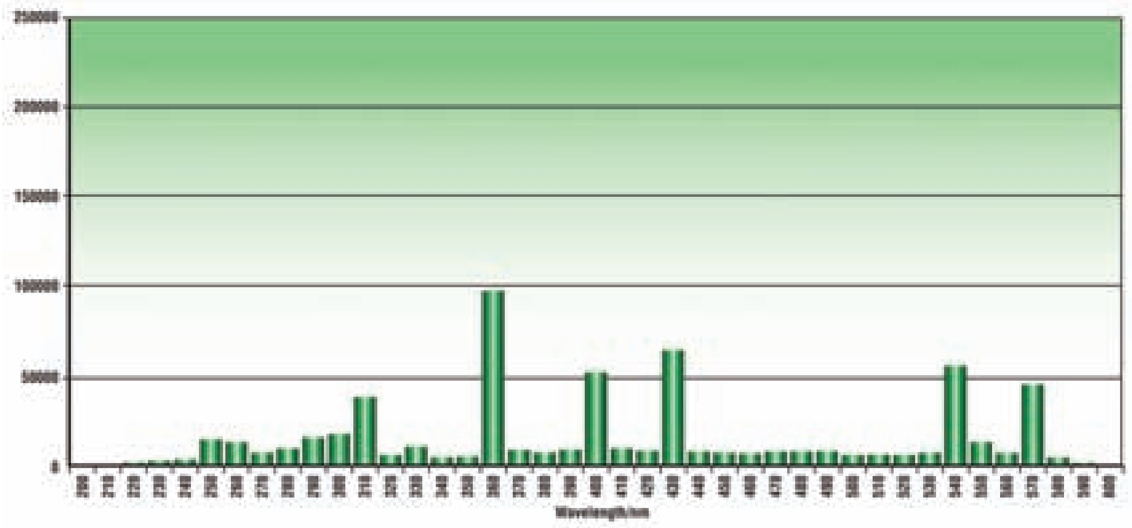
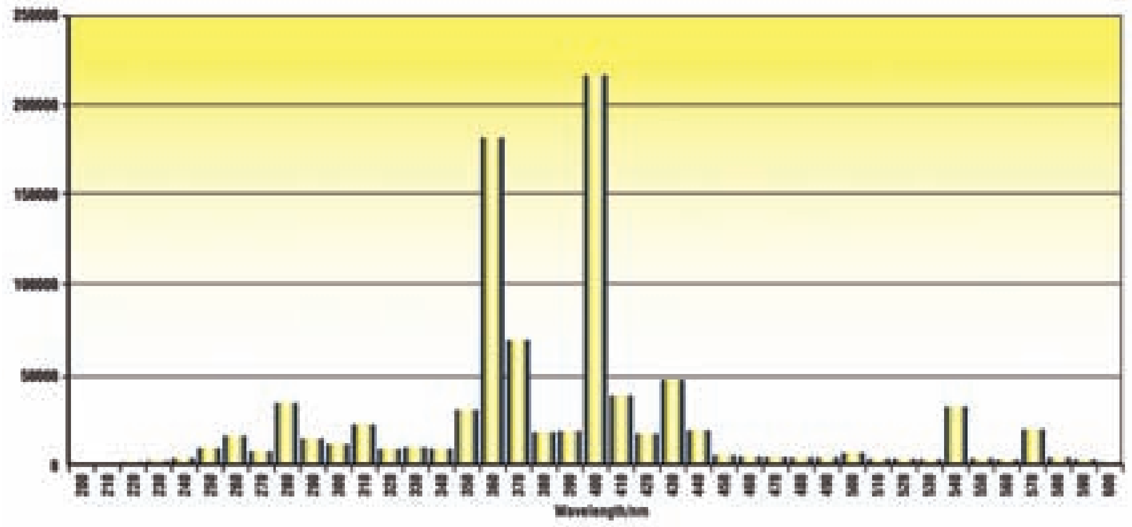


FIGURE 6

Lead bulb spectral output

Frequently referred to as the "M" bulb, it has high irradiance in the UVA and UVV range.



continuum and a series of spectral lines, which includes a characteristic sharp peak at 365 nm. This type of bulb may be utilized in applications in which a clear coat is used. Other coatings may exhibit properties that would best be cured using an additive bulb. Curing materials, such as pigmented coatings, may require the need of a longer wavelength to penetrate the material to assure proper cure. The mercury bulb does not have the required long wavelength energy to accomplish this. Adding specific elements can shift the mercury spectral output to one more suitable for the specific requirements of the material to be cured. Some examples are iron, lead, gallium and indium. An additive bulb consists of mercury with the addition of a specific element that, when carried into the plasma, shifts the mercury spectral output to a specific range characteristic of that particular element. Figure 7 compares the relative spectral output of 10-inch electrodeless 600wpi bulbs.

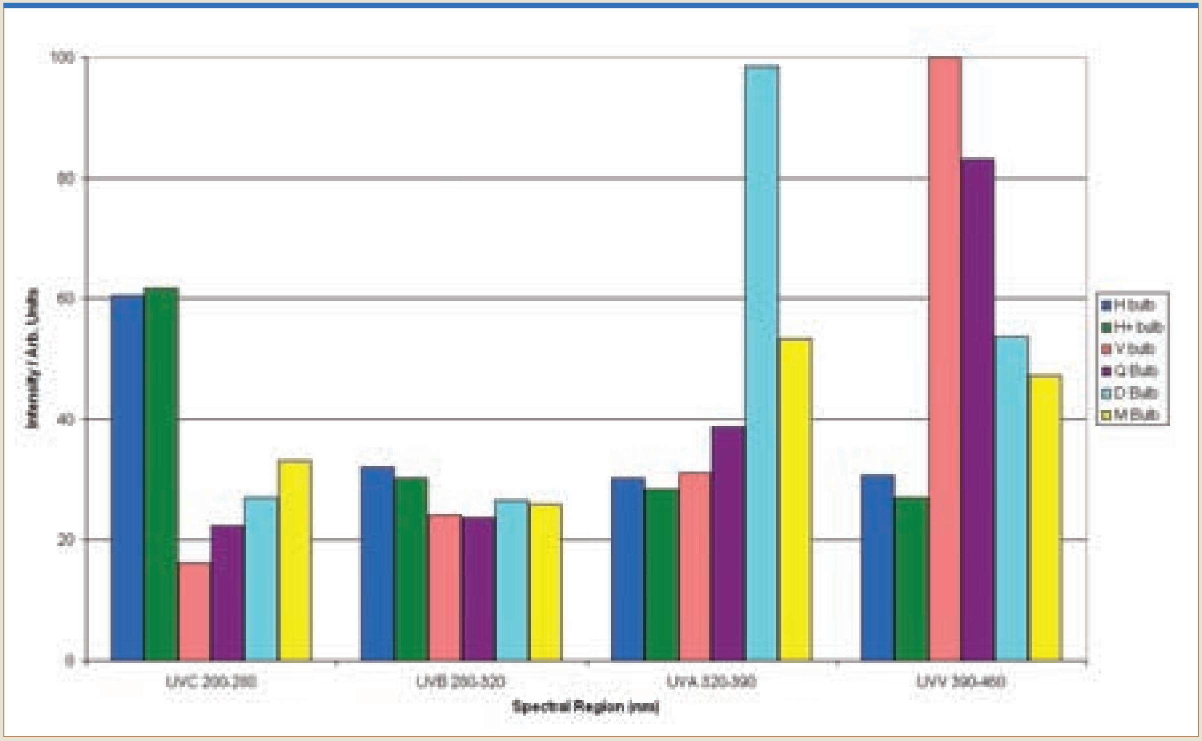
Spectral Output Stability as it Relates to Bulb Temperature

Along with the UV-bulb spectrum match to the coating requirements, temperature across the bulb is considered a critical element for success. Not only is bulb life extended through cooling of the quartz tube, it also contributes to the spectral output stabilization. Without this stabilization, the spectral output could shift, thus reducing the energy within a specific range of a bulb matched to an ink, coating or adhesive. Proper cure would be affected.

The reason for the shift is the concentration of the additives in the bulb fill. During the energizing of the bulb, the fill material's vapor pressure increases rapidly as the material approaches its boiling point and, therefore, the material is more likely to evaporate and be carried into the plasma. It is only when the additives are in the plasma that the spectral enhancement (shift) occurs. Different additives have different vapor pressures, so each will be affected by the lamp wall temperature. If the lamp wall temperature is below the material's boiling point, the additive may condense on the wall. If this temperature is significantly below the wall temperature, then the material is unlikely to evaporate off the wall and will not be available to the plasma. Moreover, if an additive spends an extended period in contact with the quartz wall, it can become immobilized there either through reaction with or migration into the quartz. This reduces

FIGURE 7

Relative spectral output of Coolwave® 10" electrodeless 600wpi bulbs



the amount of additive available to cause the spectral enhancement and the spectrum shifts back toward a mercury spectrum.

Iron-additive bulbs, in particular, are very sensitive to bulb cooling. Iron iodide boils at around 849°C at 1 atm. This value will be even higher inside an operating lamp. Ideally, the bulb wall should not exceed 800-850°C, so the resulting vapor pressure of the iron iodide is always relatively low as it is below its boiling point. Thus, if a bulb is overcooled with the wall temperature below 600°C, this can also result in the spectral enhancement reversion back to that of a mercury bulb. In excessively overcooled lamps, it is also possible to condense the mercury onto the quartz wall.

Most UV systems are designed to operate over a wide range of environmental conditions. Cooling temperature is one variable that can affect the stabilization of the spectral output. Plant temperatures, as well as ambient geographical locations, play a big part in the operation of systems throughout these varying operating conditions.

Solutions to Provide Bulb Spectral Stability

With the advancements of variable-output UV systems incorporating variable-speed fans, UV-spectral output can be stabilized when selecting a low power output. In electrode lamp technologies, a shift to digital power supplies with wide power setting ranges and the desire to cure with additive bulbs has made it necessary to control bulb temperature. This provides a more controlled process and extends bulb life.

In some systems, controlling the cooling air can be accomplished by means of fans, dampers or solenoids set to adjust cooling air depending upon the demanded power output in an open-loop control. More advanced techniques can be utilized to create a closed-loop process to ensure the cooling is always optimum. Here, a stable bulb wall temperature range would allow mercury and its additive to be carried into the bulb plasma.

It would be desirable to measure the bulb wall temperature directly, but this is not practical in the field. As a result, other means of control have to be used.

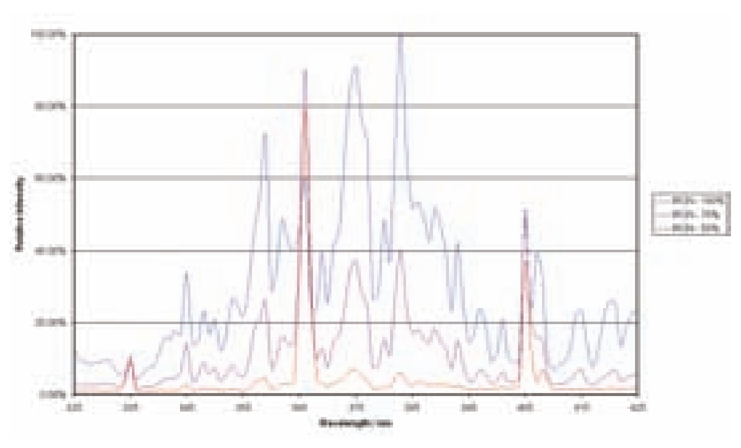
For conventional arc-lamp systems, one such method is to regulate the lamp cooling to the exhaust temperature of the cooling air or metalwork close to the lamp. This can be an effective method, but suffers from some drawbacks. First, this is subject to ambient temperature variations of the incoming air, which results in the tolerance limits having to be quite wide. Second, there is the problem of setting the cooling level while the system warms up to its steady-state temperature. Finally, temperature changes give quite a slow control response, which may not be suitable for critical fills such as iron.

A more responsive method is to use the differential pressure across the lamp head to control the flow. However, this by itself does not guarantee cooling is present because there can be a pressure differential with no flow. The best approach is a combination of actual lamp power, differential pressure and temperature sensing—which can be linked to provide very tight closed-loop control. While testing the Nordson Quadcure lamp system, we varied the output lamp power. Through the closed-loop control, the bulb temperature tracked proportionately while the spectral output remained consistent, proving our theory.

In these systems, the controller automatically calculates the desired cooling level dependent on the lamp power and adjusts the cooling flow automatically. Differential pressure sensing is used to give fine, instantaneous control via a PID loop, while the exhaust temperature sensing provides a redundant safety system. The same algorithms are used for all arc systems. Tests have shown that controlling the cooling in this manner leads to improved lamp efficiency by

Figure 8

Spectral output versus power setting for IRON 15mm OD/13mm ID 10” 600wpi bulb utilizing a constant speed blower



maintaining the optimum spectral output and reduction of volumes of cooling air required.

Similar control of the lamp cooling also has benefits for electrodeless systems. Tests, utilizing a Nordson Coolwave®2-610V system with an internal variable-speed blower, have shown that the bulb temperature is kept at a constant ideal temperature for spectral stabilization. The variable-speed blower, part of a closed-loop control, changes speed in relationship to the selected power output, thus keeping the ideal temperature across the bulb and eliminating the possibility of overcooling. Our tests have proven that these advancements assure UV-lamp spectral stabilization.

The test data presented in Figure 8 shows the effect of overcooling an iron bulb. With the system power setting at 100 percent, the iron-additive bulb displays a typical spectral output rich in the UVA range. Utilizing a constant-speed blower without closed-loop control, the UV light power is reduced to 70 percent and 50 percent. The effects are displayed with the iron spectrum reverting to that of a mercury-only bulb. Figure 9 displays the effect of a variable-speed blower used in a closed-loop control. Even at the 50 percent power setting, the spectral output is stable because the bulb temperature is kept at its optimum operating temperature to assure proper spectral emission. Additional tests utilizing the variable-speed blower, in a closed-loop control showed the iron-additive bulb spectrum is stable throughout the selected power level changes, with no UV spectral shift.

Conclusion

Utilizing closed-loop control with a variable-speed cooling blower, UV-spectral stability can be best maintained to assure better control of your UV curing process.

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FIGURE 9

Spectral output versus power setting for IRON 15mm OD/13mm ID 10" 600wpi bulb utilizing a variable-speed blower in a closed-loop control