

High Power UV Light Sources— When More is Too Much

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When evaluating specifications for ultraviolet light sources, it may be tempting to consider using one that is equipped with a high power bulb. This would seem to offer additional flexibility in configuring a particular application. As is often the case in technical product evaluations, there are more issues involved than just a single product attribute.

Among the important factors that require consideration when evaluating competitive light sources are:

- System Efficiency
- Spectral Output & Control
- Optical Power Control
- Adhesive Response

Ignoring or improperly assessing these topics can easily lead to inappropriate equipment selection that results in reduced manufacturing efficiency, inconsistent curing processes or increased maintenance costs.

System Efficiency

Most ultraviolet sources use an arc lamp to generate light. There are many different lamp configurations and design factors that affect the performance and output from a spot curing system. Table 1 compares manufacturer's published data for several commercial spot curing products that use mercury arc lamps as their light source.

It can be clearly seen that increasing the lamp's electrical power rating does not imply that a proportional increase in deliverable light will follow.

Delivering ultraviolet light from the lamp to the actual target area is just as important as generating light in the first place. With spot curing systems, a number of optical and engineering issues require appropriate consideration to maximize collection and delivery of output from the lamp. In particular, poor coupling of the lamp output into the optical delivery system is a very important barrier to high system efficiency.

Optical energy that cannot be delivered to the target will be converted into heat. Systems that do not exhibit high optical efficiency will run hotter, which can have a direct impact on the service life of the arc lamp and can cause premature degradation of liquid filled light guides. Both of these consequences contribute to increased operating and maintenance costs for the system, resulting in a higher cost per finished assembly.

Example	Lamp Power (Watts)	Output Irradiance (mW/cm ²)
EXFO Novacure®	100	23400
Competitor 1	100	12000
Competitor 2	100	5000
Competitor 3	200	> 7000
Competitor 4	200	18000
Competitor 5	200	7500

Table 1: Manufacturer's published data for UV Light sources using Mercury arc lamps

Spectral Output & Control

When the pressurized contents of an arc lamp are energized to a plasma state, light is emitted. The resulting output is actually composed of energy spanning a large portion of the light spectrum, from the ultraviolet range, through the visible and into the infrared region. Figure 1 shows the output distribution of a typical mercury vapor arc lamp.

Several peaks can be seen in the output distribution. The composition of the material inside the lamp and the pressure of the contents determine the spectral distribution. For example, high-pressure lamps operate with internal pressures greater than five atmospheres.

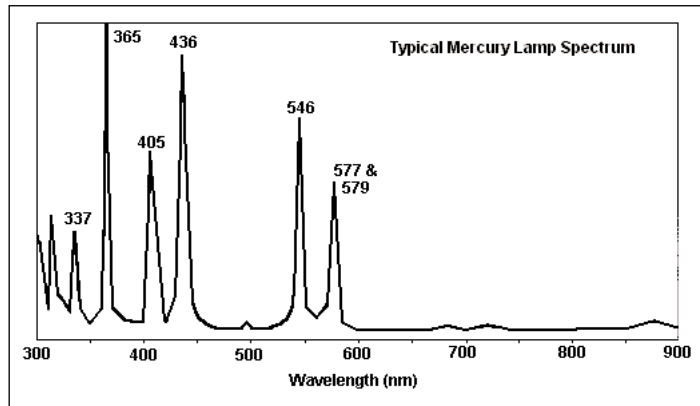


Figure 1: Typical Mercury Arc Lamp Output

The output of high-pressure mercury arc lamps tends to have broader spectral peaks and is shifted toward longer wavelengths, when compared to low-pressure lamps. Figure 2 displays the output from a high-pressure lamp, which is mounted in a reflector having a dichroic coating to virtually eliminate output in the infrared range.

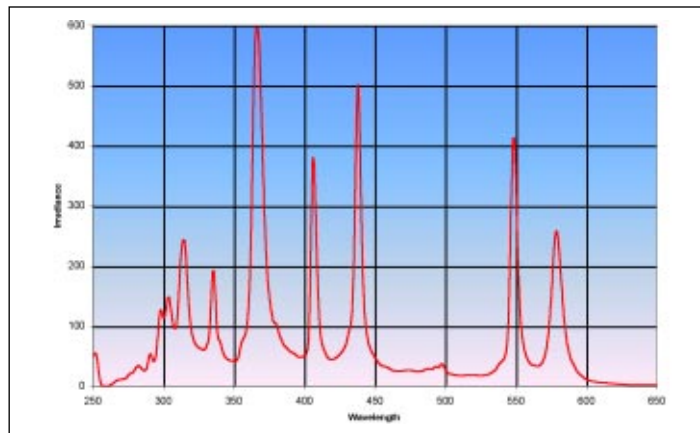


Figure 2: High Pressure Mercury Lamp Output

Introducing small amounts of material other than mercury can modify the lamp's output in particular spectral regions. Iron is a popular additive, used to enhance the visible portion of the spectrum, while flattening much of the ultraviolet range.

A more flexible method to refine the output from a light source is through the use of interchangeable optical filters. Application requirements—often driven by the choice of adhesive or coating and the materials being bonded—can be more easily met when a number of filter options are available. As an example, a 400 to 500 nm bandpass filter would change the profile from Figure 2 to that shown in Figure 3.

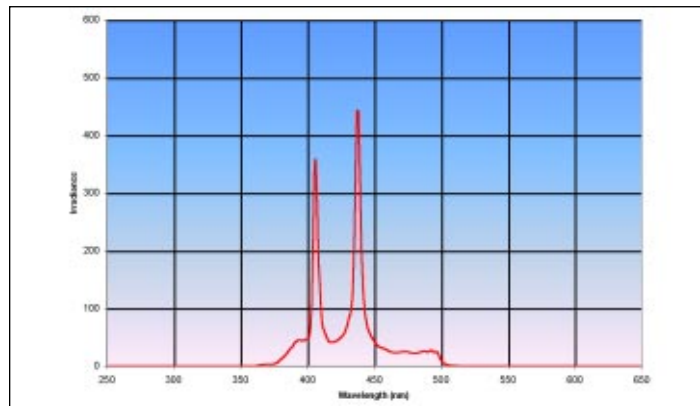


Figure 3: High Pressure Mercury Lamp using Visible Light (400-500 nm) Filter

The availability of a range of filters provides the most flexibility in tailoring spectral output to the application requirements. Some considerations for filter selection are shown in Table 2.

Filter Range (nm) Range (nm)	Notes on Typical Applications	Max. Irradiance (mW/cm ²)
320 – 500	General Purpose - suitable for most UV and visible light curing Epoxy and Acrylic adhesives on a broad variety of substrates.	23400
400 – 500	Visible light output - used with visible curing Acrylic adhesives, particularly when UV-sensitive substrates are involved.	8700
320 – 390	Narrow band filter - some Epoxy adhesives have superior response to this filter. May also be used when unwanted substrate heating results from visible light irradiation.	11100
365	Peak filter - May be used when unwanted substrate heating results from UV and/or visible light irradiation.	6000
250 – 450	Provides some UVC input that can be helpful for certain Epoxy adhesives, as well as surface curing of Acrylic adhesives. Must be used in conjunction with an Extended Range liquid light guide, or a quartz fiber light guide.	24600

Table 2: Applications of Different Output Filters

Optical Power Control

The consistency of the desired optical output is an important factor in establishing and maintaining a high yield manufacturing process. It is an inescapable fact that mercury arc lamps degrade with use. Without special measures, a standard mercury arc bulb can lose *fifty* percent of its initial output during the first three hundred hours of operation.

Improved engineering methods for driving the lamp can extend the half-life point significantly, as shown in Figure 4. This has a favourable impact on process economics, because material and labour costs—in addition to process downtime—are substantially reduced.

As will be shown in the next section, consistent and repeatable curing of an adhesive requires repeatable light exposure. While the rate of change in output from the arc lamp can be reduced, additional controls are needed to provide consistent output through the life of the lamp. This is best implemented through a feedback system that monitors bulb output and makes appropriate equipment adjustments to control the light delivery.

Our patented approach to solving this problem employs a beam splitter in the optical path, coupled to electronics that control a variable aperture. As lamp output begins to decline, this is detected and the aperture is opened slightly to maintain the desired optical power. At some future point, when the aperture cannot be opened further, the system will trigger an alarm signal to indicate that lamp replacement is required.

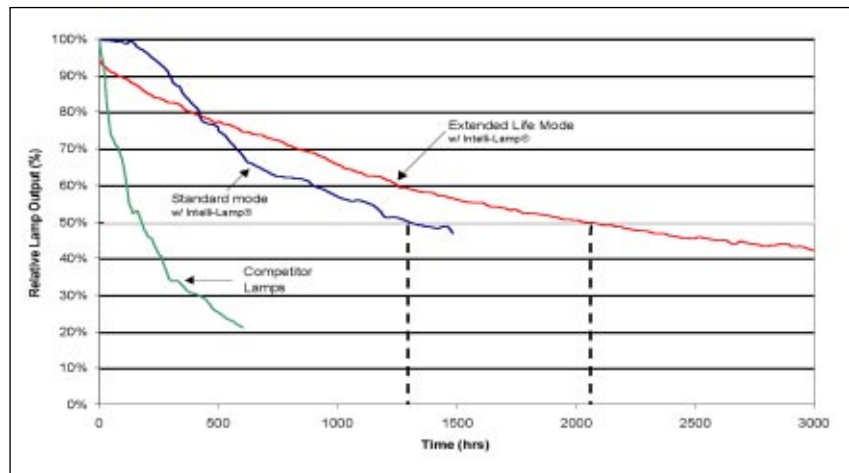


Figure 4: Arc Lamp Power Degradation

This advanced design helps to ensure that process variations associated with light curing are minimized and contribute to improved production yield levels.

Adhesive Response

The spectral input delivered to the adhesive can have a significant impact on the properties developed. Figure 5 compares the Shore Microhardness evident in a popular, unfilled, UV-cured epoxy adhesive. Each group represents equal total energy delivered to the samples. For this material, it can be seen that one of the filters (320 - 390 nm) dominates in producing superior results.

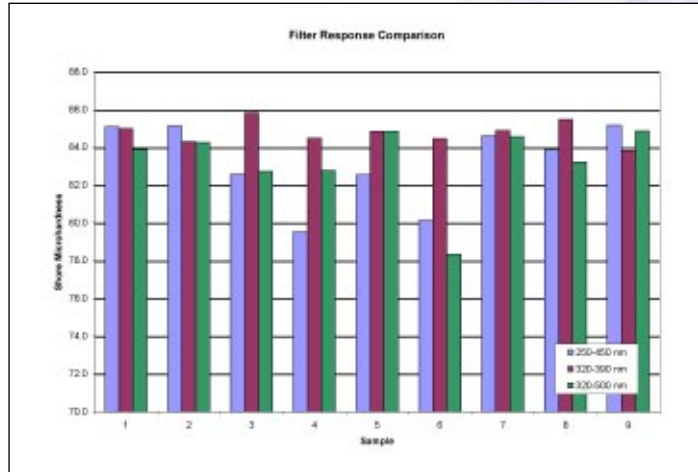


Figure 5 : Adhesive Response to Spectral Input

Attempts to augment production throughput, by increasing the intensity while decreasing exposure duration, may not always meet with success. It is well known that curing an adhesive too aggressively can result in residual stress or excess shrinkage in the adhesive.

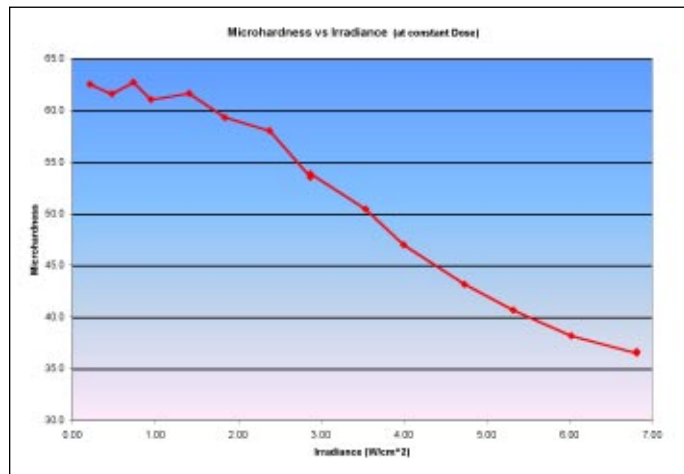


Figure 6: Adhesive Response to Changing Irradiance (at constant Dose)

Understanding the response of the adhesive to higher irradiance levels is a key factor in determining the potential impact on the physical properties of the material, as well as the potential for increased—or reduced—process yield.

Figure 7 shows that the Shore Microhardness values for a particular adhesive actually decrease with higher intensity exposure. The microhardness of many adhesives can be taken as a good indicator of degree of cure for the material. For the data shown, the total amount of energy delivered to the samples was held constant, while intensity and time were varied. Clearly, this material will not respond well to attempts to increase production rates using the standard approach.

Application Note

For an adhesive such as this one, a further impact can be noted. When the light source does not provide for maintenance of a consistent irradiance level, adhesive performance will change dramatically during the life of the UV lamp.

Several other adhesive properties can vary with changes in exposure parameters. Some will improve, while others degrade. Figure 7 compares the response of three adhesive properties to different, but equal-energy cure profiles. The low end of the scale represents an irradiance level of approximately 500 mW/cm², while the high end is about 16,000 mW/cm².

For this material—a popular, filled acrylic adhesive—both volumetric shrinkage and moisture absorption were reduced using a high intensity exposure. However, the glass transition temperature was also reduced.

Figure 8 shows the comparable responses for a popular, filled epoxy adhesive. With this material, the changes in properties are similar to the previous one, except for the T_g response, which appears to increase at higher irradiance levels.

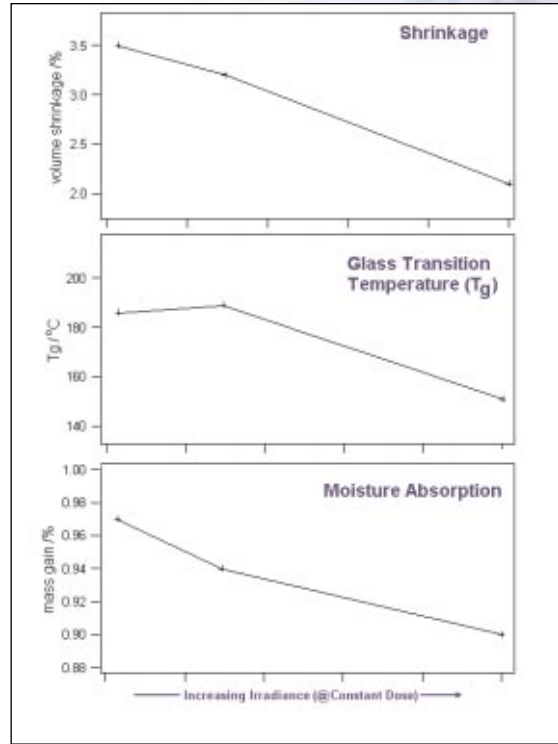


Figure 7: Property Responses Compared

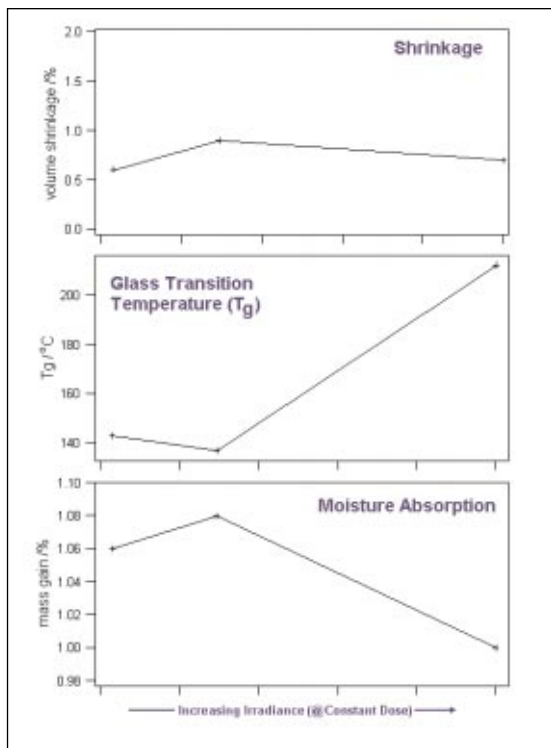


Figure 8: More Property Responses

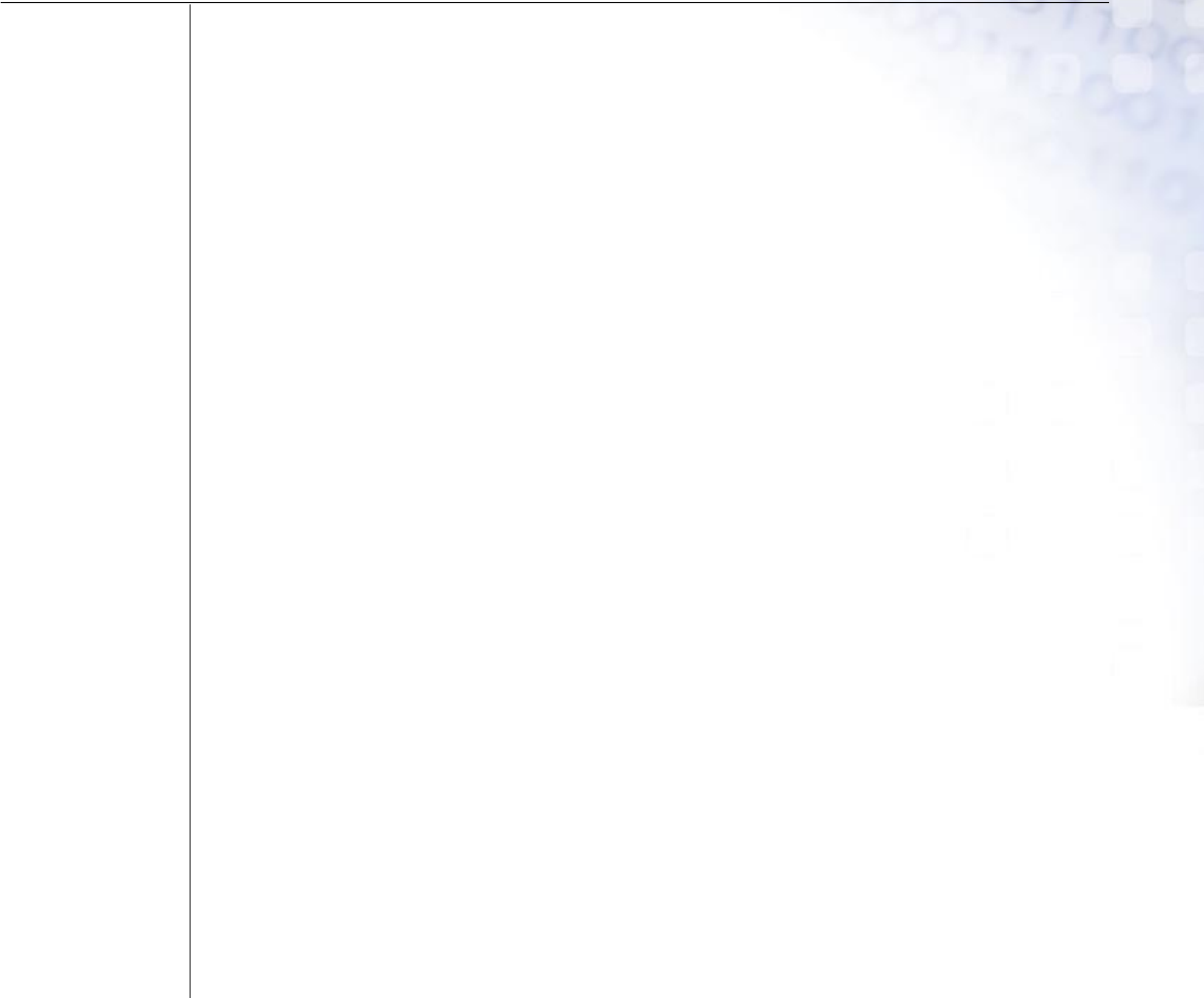
Understanding how adhesive properties will develop under different exposure conditions is an important consideration when working to increase production throughput. Should the changes be sufficient to affect process yield, the final result could as easily be a drop in the production rate of acceptable components.

Summary & Conclusions

Several product attributes influence the most suitable choice of an ultraviolet light source. These include the system efficiency, spectral output and control mechanisms available, as well as the physical response of the adhesive being cured.

It has been shown that a higher power rating for the ultraviolet lamp itself does not typically result in proportionally increased output from the equipment. We have also shown that adhesives may not respond as may be expected to when exposed to different cure conditions—particularly increased irradiance levels.

As a result, it becomes important to thoroughly assess these factors when making a choice among Ultraviolet curing light sources. Taking an informed approach in selecting such equipment will support the process goals of performance, repeatability, reliability and lowest cost per completed assembly.



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