UV Lamp Performance Over Time

Stephen B. Siegel

UV Process Supply, Inc.

Chicago, Illinois USA

In this study, we review the ultraviolet lamp as the variable of primary concern in the UV curing process. We have performed two tests: one which displays graphically how an individual UV lamp degrades over time, and another which shows how one UV lamp compares to another. We will discuss all these results in terms of intensity at critical wavelengths.

INTRODUCTION

UV lamp performance has classically been characterized by the use of two distinct methods. Many production facilities employ indirect mechanical testing of the resultant products, which makes assumptions about the output of the UV lamp based on cure characteristics of the product, and which may have a multitude of undiscovered variables attached such as heat effects, oxidation effects, or infrared effects.

The second method, a more direct (but limited) radiometric measuring device, produces a "snapshot" of the lamp's performance at the moment of its use. Collecting data as it moves through a process, radiometers sample conditions at a fixed rate, but often are only used at the beginning of a production run, or maybe periodically to "spot check" the process on important jobs.

Many companies involved with UV curing continue to experience problems with their curing systems, either intermittent product failures, or entire runs which do not meet quality control standards even though they were "produced under the same conditions" as jobs which passed those same standards. The introduction of other variables into the curing equation is the obvious answer, but isolating and identifying those variables is nearly impossible with the tools at hand. With only the mechanical tests of failed products, or even the radiometer readings at job start to provide raw data, assumptions about cause and effect are called on to fill in the holes in our knowledge.

More recent technology, though, now enables UV users

to see why many of these failures occur on a continuous basis, and can provide insight into what steps to take to eliminate or curtail the unwanted effects, and generate consistent production output.

THE TEST INSTRUMENT

The monitoring system used for our tests consisted of the LM-9000 UV Lamp Monitor from UV Process Supply, an analytical tool designed for directly measuring the output of UV lamps while on-line, operating inside the curing system. The PC-based computer hardware and software based data acquisition system worked in conjunction with an optical probe, fiber optic cabling, an optical bench, sensor unit.



The optical probe, which has a rated maximum temperature of 400°C, is mounted within the lamp reflector housing or clipped directly onto the lamp (see Figure 1). It is connected via fiber optic to an optical bench, mounted on an internal P.C. card or in an external

Figure 1

case (attached via serial cable). This unit splits the incoming light "signal" from the fiber optic into its various components (Wavelengths). An array of 1100 sensors then converts this wavelength information into electrical signal voltages which the lamp monitoring software measures and manages.

The software displays the Wavelength Intensity Distribution between the 200nm and 450nm wavelengths in real-time, sampled approximately every 5 seconds. All wavelengths within the range (all 1100 data points) were examined at each sampling. Particular wavelengths were selected for special attention, such as to generate "Events" or to signal various simulated phases of actual production runs (Start, Stop, Change Power Settings, etc.). The Life of Lamp Test (single lamp) data was collected from a 10" arc length lamp, at 750 watts per inch, over it's actual life of 408 hours (18 days) continuous use before failure. The Lamp Comparison Test data was collected from 14 lamps, all 20" arc length, at 300 watts per inch, each lamp run for 15-20 minutes, but sampled only after lamp stabilization had occurred. Two (2) were brand new, the others were returned from production environments after 1000 hours of use. Some of these lamps were of foreign manufacture, while others were of US-origin.

THE BASELINE OF A LAMP

Every UV lamp produces specific wavelengths of light associated with the materials inside the lamp (i.e. mercury, metal halides, et.al.). Each lamp produces its own Wavelength Intensity Distribution over its given range (usually between 200nm and 450nm) which can be viewed as its signature.

Certain frequencies within this range are important to the curing process, and the others are either unnecessary, or harmful, to that specific process. Photo initiators can respond, to greater or lesser degree, at various frequencies. Once power has been applied to a lamp, it goes through a "warm-up" period, during which time it's output levels are unstable. This makes the lamp an unreliable curing instrument until stabilization occurs.

We observed that this warm-up period is different for every lamp and power supply combination, lasting for between 5 and 15 minutes, during which intensity of the various wavelengths fluctuate wildly. Some wavelengths can reach 150% of their operating maximum before settling down, while others do not approach 100% until lamp temperature reaches some critical point.

Once the lamp has reached this stabilized state, we save all associated values to form the "lamp baseline". By saving the signature of the lamp when it is "new" or newly installed into the curing system, we have a permanent set of baseline values to use for comparison at any time in the future.

ENERGY OUTPUT EVENTS

From lamp start, when energy output of all wavelengths was "zero", through the warm-up period, to the time when output characteristics appear to stabilize, the particular wavelengths showing the highest intensities (or peaks) changes as the lamp proceeds to its operating state. Radiometers give readings showing total energy output (in mJ/cm2) on a narrow range of wavelengths, presumably some of those same high-intensity peaks, sampled at a given rate, such as 40 samples per second. Such devices may show the same reading even though the actual wavelengths of light being output is rising or falling within the range.

As an example, from lamp start until three minutes had elapsed, one lamp displayed peaks at 350nm, which after four minutes became two lower peaks both above and below 350nm. Total energy of the individual 350nm peak was about the same as the two lower adjacent peaks. This type of behavior would not be differentiated by the "snapshot" method of a radiometer: both would have given similar results even though the actual output frequencies were different (see figure 2).



By using the baseline of a lamp obtained previously, and comparing it to the present state of that lamp (which was just started), a real-time display of percentages at the six selected wavelengths allowed us to see when the lamp stabilized. This stabilized state was defined by viewing this percentage display and noting when the intensity values no longer increased.

Once the intensity levels of the various wavelengths had stabilized, the warm-up phase ended and the simulated job start would begin, as in a production environment. We set up our instrument to save a job baseline of all wavelengths, the simulated job would then proceed with subsequent samplings occurring at regular (under 5 seconds) intervals.

This regularly sampled data could be saved at either regular intervals or saved only upon an "Event", such as when any monitored wavelength's intensity level fell below 25% or 50% of it's baseline value.

LIFE OF LAMP TEST

We monitored one lamp (750 watts per inch) running continuously for 18 days (408 hours) until its failure, in order to determine an individual lamp's performance characteristics. As a lamp experiences continuous use, we expected to find that lamp intensity in general degrades over time. As the contents within a lamp experience changes in pressure, as the electrodes inside the lamp decays and deposits material on the interior quartz, and possibly as the quartz itself changes with temperature, the lamp's overall output degrades.

What we observed, however, is that certain wavelengths exhibit straight line decline in intensity while others show oscillating declines, with peaks, valleys, plateaus and dips having a generalized trend downward. Those wavelengths with greatest intensity tend to exhibit this agitated decline while wavelengths of lower intensity tend to exhibit more straight line behavior (see figure 3).

Our most startling discovery to date is that there does not appear to be any uniformity, or even any simple trend, to this degradation. Different wavelengths degrade at different rates. The percentage of energy loss over the life of the lamp shows clearly that 254nm suffered the steepest decline in intensity while 365nm held up the best over time.

We have observed that subtle variances in power supplied to a lamp affects its output. When a factory up the street starts up or shuts down, an "Event" would be triggered, alerting that lamp behavior had changed.

Similarly, changes in ventilation, as well as the individual operating temperature of the lamp, had profound effects on the intensity distribution of that lamp. If ventilation air is blown across a lamp, the air temperature may cause the intensity of specific wavelengths to drop significantly from the lamp's baseline. Natural convection was chosen for these tests to help eliminate this variable from our results.

LAMP COMPARISON TESTS

In order to perform a broader examination of lamp characteristics, we monitored 14 lamps of the same specification: 20" arc length, 300 watts per inch. Some were new, some had over 1000 hours of service, some were made in the United States, while others were of foreign manufacture.

All lamps were installed into the same testing enclosure, provided with the same line current and power supply, and run under the same conditions. The same testing instrument was used to obtain all the results.

The intensity levels of a range of similar lamps at a particular wavelength varies. When looking at the six different wavelengths we were paying special attention to (see figure 4), each lamp in the series displayed distinct intensity levels at each wavelength, though they do tend to congregate around a certain level. Output measured at 254nm tends to congregate around an intensity index value of 250 whereas output measured at 365nm tends toward an intensity index value of 3000.

The degree of separation lamp-to-lamp, between index values of individual lamp intensities at these pre-selected wavelengths, can also vary widely. Some of the selected wavelengths held tightly together, with less than 5% variation lamp-to-lamp, while others changed considerably.

Further, some "used" lamps (with over 1000 hours in service) produced higher intensity levels at critical frequencies than did comparable "new" lamps, or used lamps with higher or lower hours (see figure 4). We may be observing variances in internal lamp conditions, where a particular lamp's electrodes have decayed or changed conductance.

We had seen that with any given lamp, the individual wavelengths degrade at individual rates, some displaying marked fall off (40% or more from baseline) while other wavelengths remain strong (within 15% - 20% of baseline). Some uniformity in degradation of lamp performance between similar lamps would be expected, given general entropy effects and the observed variances in specific wavelength output.

However, we have seen no true pattern of decay between similar lamps manufactured by the same company, much less by similar lamps produced by different lamp manufacturers. Lamps produced on the same day, to the same specifications, by the same manufacturer exhibit different operating characteristics over time, even within the same curing system.

At different power supply settings on the same lamp, we have also observed non-linear variances in intensity within the selected wavelengths (see Figures 5a, 5b, 6a and 6b) the same group of lamps were tested at high and medium power settings, 300 watts per inch and 200 watts per inch respectively. The notion that decreasing the power level decreases the intensity of all the individual wavelengths within a lamp proportionately, would produce a set of graphs that look identical, except for the intensity level (i.e.: the height of each bar in the bar graph, or the starting point of the line graph).

While the graphs are similar, they are not quite proportional, with some lamps exhibiting a noticeable difference in output wavelength intensity when compared to others which did perform more proportionately. Again, new lamps did not distinguish themselves from used lamps in these regards; they were not any more linear in behavior than the lamps with 1000 hours of use.

CONCLUSIONS

Many factors influence the level of cure within a process. Higher power lamps, newer coating formulations, new trends in cooling and IR/UV filtering have all contributed greatly to a more stable, and hence, reproducible finished product. The improvement in control systems and tools such as radiometers, helps promote ever higher quality control standards. But, if the underlying mechanism for obtaining cure, the UV lamp itself, is not providing long-term, stable output at the required wavelengths, the entire process can be compromised, or even inhibited.

Based on our findings, finished product failure could still result even though all the periodic spot-checks indicated a successful production run. The continuous fluctuation of lamp performance has underscored the need for more stringent quality control standards and monitoring equipment.

We have observed the individual lamp performance over time and found various wavelengths loosing intensity at different rates over the life of the lamp.

We have observed that similar lamps do not have the same Wavelength Intensity Distribution signatures.

We have observed that a lamp's baseline performance characteristics and subsequent degradation from baseline are not linear for every frequency within it's output range.

We have observed that a lamp's baseline performance characteristics are not linear for every frequency within it's output range at different power settings. We have observed that lamps with the same arc length, same power rating and even same manufacturer produce different Wavelength Intensity Distribution signatures.

We have observed significant changes from Baseline during the course of a job, or over the course of several weeks of operation, and in general over the life of the individual lamp.

All of these incidents lead to an unstable/stable, not very reproducible end result. Thus the characteristic Wavelength Intensity Distribution signature of each lamp plays a major role in it's long term use as a reliable curing instrument.

Fluctuations in power, both the external (utility supplied) line power characteristics as well as the individual lamp power supply, may certainly be responsible for some of the observed effects. Similarly, the amount of ventilation, and how it is supplied to the individual lamps may have observable effects on the operating behavior of the lamps. Further testing in these areas will be done over the next few months to determine their relative impact on the results obtained so far.

Continuous lamp monitoring, and event driven responses to run-time conditions, is clearly called for, in order to reduce the occurrence of problems. Only through real-time examination of lamp output can we avoid the pitfalls of current production methods, because periodic spot-checks are rarely performed at the moment they are needed, when the lamp is not producing the required intensity at the required wavelengths.



Figure 3



Figure 4



Figure 5a



Figure 5b

























