FEATURE

The Importance of Real-Time UV Monitoring and Measurement

By Paul Mills and Jim Raymont

"When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind." —Lord Kelvin

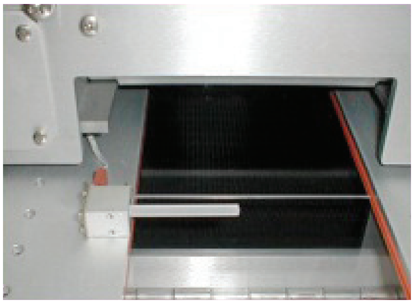
Once upon a time, gas stations were called service stations and they had a team of attendants to pump your gas, clean your windshield and lift the hood to check your oil every time you filled up…and gas cost less than 30 cents per gallon. For many of today's newest drivers, this is as much of a fairy tale as Cinderella or Snow White.

Is it any wonder why automobile designers install both oil dipsticks and dashboard oil warning lights? Wouldn't just one of these suffice?

Obviously, while these measurement devices are related, they measure different oil properties and have markedly different functions. The risk of driving your car without enough oil is important enough to merit constant vigilance. You obviously can't check the dipstick while driving. On the other hand, the need for absolute oil level measurements during maintenance (such as oil changes and tune-ups) or to provide mechanics with a quantitative measurement when diagnosing engine problems requires the dipstick.

Despite the risks, most UV systems operate without a warning light or a dipstick.

Even the best managed production lines too often rely only on periodic checks with a belt radiometer as the means of measuring UV cure. But, like driving without a warning light, the potential damage that can occur by operating a UV line without a warning light should stop operators in their tracks and cause them to



Installed sensor with quartz rod to pick up UV energy.

consider the value of adding real-time UV measurement.

After having worked on literally hundreds of production lines, it seems ironic that while almost no system designer would supply a thermal convection oven without a process thermocouple, we rarely see a system with a real-time UV sensor installed.

This is ironic considering that UV curing is often associated with high-speed production for things such as printing, optical fiber, packaging, CD/DVD manufacturing or high-speed wood finishing lines. These are applications in which an undetected problem could mean hundreds, even thousands of bad parts in just hours. By the time these users break out their belt radiometer it's far too late.

The big three automakers tackled this problem during the 1990s when they drafted the QS-9000 standard that required process monitoring rather than allowing suppliers to rely on finished parts inspection alone. They realized that preventing defects and not just fixing them was the key to cutting costs.

Fortunately, the technology to continuously monitor UV curing not only exists, but is easy to implement and cost-effective. This paper will describe what to measure to safeguard your line and how to do it. We point to systems that range from simple "go/no-go" indicators to advanced but cost-efficient interfaces that will send a text or e-mail message when something goes wrong.

Changes to UV Output in the Real World

In day-to-day operation, UV lamps (particularly arc lamp systems) show a pronounced drop in irradiance over time. Like a spark plug, continuous and repeated use cuts the lamp's life from the first time it's fired. It's not unusual to see a 50% change in output after less than 1,000 hours of use.

Cleanliness of the reflector, changes in cooling and power supply problems can all impact irradiance. So can any changes in the distance of the lamp to the part or angle of the bulb that might occur from handling during maintenance.

What to Measure?

There are two parameters of UV curing that most users should measure regularly; peak irradiance and energy density. Let's take a quick look at what each of these terms means.

Irradiance

In layman's terms, this measures how "bright" the UV lamp is. Irradiance can be affected in a number of ways—by "increasing the wattage" just as you might by switching from a 25W to a 60W light bulb, or by "turning up or down" the intensity through a variable power supply. The common measure of irradiance is Watts/cm^2.

Energy Density

Time is the second factor critical to proper curing and this is referred to as energy density. You may also hear it called "dose" even though this term does not accurately fit. As sun-tanners can attest, it's not just the intensity of the UV source that produces their glow, but exposure time. A few seconds in even the brightest sunlight won't produce a bronzed body.

To produce properly cured products, both irradiance and time must be within the prescribed material specification. Like most cooking recipes that require a certain time and temperature, UV recipes usually require minimum irradiance and exposure time (energy density). The common measure of energy density is Joules/cm^2. (This is a simplification and assumes that you have the right type of UV source for your formulation and that other process parameters are controlled and maintained.)

Belt Radiometers Versus Online Sensors

The conventional approach to checking UV-system performance usually relies on running a logging radiometer through the system. The belt radiometer is the ideal tool for this purpose.

The latest generation of belt radiometers record peak irradiance and energy density over a number of important UV bands simultaneously. Since the belt radiometer mimics a production part, it provides very useful information about the UV exposure of production parts.

Example of a radiometer that displays irradiance and energy density.

The belt radiometer, like the car dipstick, provides an absolute, quantitative evaluation of cure. Its values can be compared to the material specification as an indicator of how the process is running, and provides enormous insight when troubleshooting is needed.

But since it is a data-logging device, it cannot provide the continuous, real-time monitoring needed to detect problems that might occur between data collection runs. For these continuous measurements, a simple sensor integrated into the process chamber or installed into the UV source itself provides a simple but effective solution.

These sensors provide continuous irradiance data which, when combined with line speed monitoring and control, provide an added layer of process security. So the prudent operator should utilize both tools. A logging belt radiometer for quantitative, absolute data required for establishing, optimizing, maintaining and troubleshooting the process—and a compact, online sensor to continuously watch for changes in UV output. Again, these devices aren't any more redundant than a dipstick is to a warning light.

Selecting and Installing Real-Time UV Monitoring

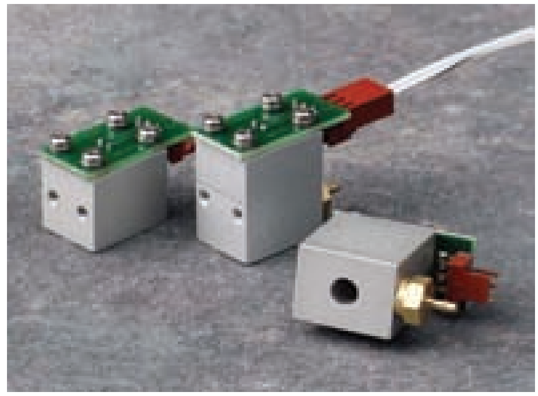
Having determined that a warning light on your UV line can save time, money and perhaps some gray hair—how should this device best be designed and integrated into the system?

The best solution embodies a few topics—sensor selection, sensor placement and data handling.

1. Sensor Design and Selection

The ideal UV sensor must embody a number of features. First, it must be compact enough to be located in the system, often in close quarters, without interfering with the production process. Today's sensors measure as small as 0.57" x 0.60" x 0.75" (1.45 x 1.52 x 1.91 cm), making them a truly compact device.

These sensors are even available with a purge design which allows a whisper of low-pressure air or nitrogen to keep the sensor window clean even in dirty environments where airborne contaminants might interfere with measurements.



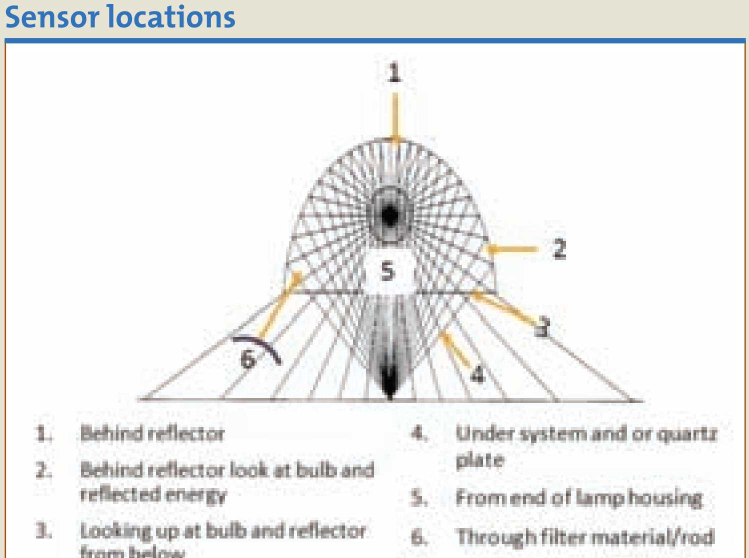
Online sensors.

The sensors are available in a variety of fixed spectral bandwidth responses (UVA, UVB, UVC and UVV) that cover short-, mid- and long-wave UV. Each sensor incorporates a single bandwidth in the optics of the sensor. The actual bandwidth that users decide to use for the sensor is based upon a combination of things, including formulation, lamp system, bulb type (mercury or mercury-additive), process window and application. An application with a relatively steady UV source can go "out of spec" because reflectors and/or quartz plates/tubes get dirty and less UV is transmitted to the cure surface. In other cases, it is more important to monitor changing output conditions from the actual source. Some customers may decide to monitor the source with a long-wave sensor (UVA or UVV) and reflectors with a short-wave (UVC) sensor.

One of the daunting challenges for sensor design is making a unit tough and stable enough for the extreme exposure in high-intensity UV applications where extreme UV irradiance and heat are common. The compact sensor has been designed to withstand thousands of hours of direct exposure to UV without noticeable degradation. For example, solarization (which is the deterioration of optical components common with exposure to intense UV energy) has been virtually eliminated in the latest generation of sensors. These sensors supply an analog output signal, proportional to the UV intensity, to an electronic interface.

FIGURE 1

Sensor locations



2. Sensor Location

While the compact and rugged design of the sensor provides a great deal of flexibility in where the sensor can be mounted, some locations make more sense than others.

Locating the sensor near or in the lamp itself has several advantages, since it provides the most direct measurement of the UV source. The sensors have a narrow field of view and on multilamp systems individual sensors can supply data for each lamp without the confusing effects of exposure to several lamps at a time. But great care should be taken when mounting a sensor in the lamp housing and the lamp manufacturer needs to be consulted. The sensor should not interfere with the proper or safe operation of the lamp.

Fortunately, a few lamp manufacturers are now warming to the idea of installing these sensors in the lamp during construction. The relatively small incremental cost of this valuable feature makes sense and we expect to see more lamps with built-in monitoring in the future.

Sensors can be installed viewing the lamp in many locations, provided that the temperature is below 100°C. Typically, a sensor just a few inches from the lamp will provide suitable conditions. Adjusting the sensor so that it "looks at" the reflected light and not directly at the bulb provides useful data, since the condition and efficiency of the

Display with single sensor.

reflector can account for a significant proportion of the UV available for curing (and is directly proportional to the direct output of the bulb anyway).

Alternatively, the compact sensor can be installed in the process chamber where it observes the lamp or reflected light. Recall that with online monitoring we are more concerned with relative, minute-to-minute changes in measured UV rather than in the value of the absolute reading itself. This premise allows greater latitude in locating sensors.

3. Data Handling and Integration

Assuming you have chosen the right sensor and properly positioned it to monitor your lamps, the only remaining question is what to do with the sensor output.

The sensor provides an analog signal that varies proportionally with the incident UV energy. Sensors can be connected directly to a self-contained, pre-engineered interface which provides a real-time readout, alarms and other features, or connected to a standard DIN rail signal processing module that converts the signals into a standard 0-10 volt signal that can be utilized by industrial PC or PLC control systems.

Display with four sensors.

The simplest UV-intensity display module provides a straightforward display of a single lamp's status. The module provides the capability of setting a reference point, typically the 100% output level of a new lamp. The digital readout shown on the panel-mounted unit can then provide a continuous "percent-of-power" reading that compares the current conditions to the UV conditions when the bulb was new and reflectors were clean. A user-settable, low-threshold limit can also be programmed into the module that will provide both a visual warning light (your dashboard oil light!) and activate a relay closure so that additional actions can be triggered when the lamp is not operating within the process window. These simple pre-assembled panel-mount modules are easily integrated into any existing system and engineered to be easily installed in the system electrical enclosure.

A more sophisticated, four-lamp version of the panel-mount display, dubbed Multibrite® allows simultaneous monitoring of four sensors. A user-selectable dial on the interface allows the percentage of full power of any of the four sensors to be displayed, as well as quick visual monitoring of the status of all four lamps with audible and LED alarms and relay closures. The Multibrite® is fully assembled and self-contained, and is supplied in a standard 19' rack-mount enclosure for easy installation.

For those plants that desire a more customized solution, the compact sensor and DIN rail transceiver are the building blocks for a completely flexible architecture. The module processes the compact sensor signal and provides a corresponding 0-10 volt analog signal that can be fed to an appropriate PLC or PC control system. Customized screens (including password protection, alarm thresholds, data graphing, data export for statistical process control and other features) can be designed.

Beyond Bells and Whistles

While the oil pressure warning light analogy might suffice to underscore the importance of constant

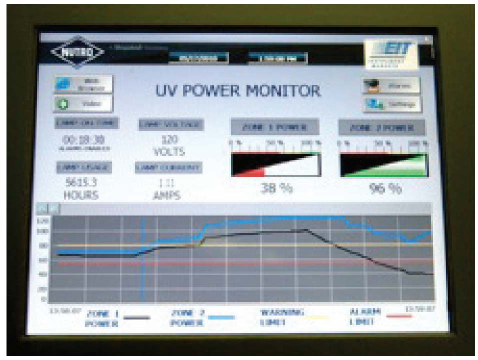
For feedback to PLC.

monitoring, it falls short in some respects. Unlike a dashboard, UV system controls are often not right in front of the key personnel who must know when something has gone wrong. The power of today's computer interface can provide that flexibility.

UV alarms can be sent immediately by e-mail or text message to any technician's or supervisor's telephone or PC with detailed information about the alarm conditions.

Remote access via any computer with access to the Internet allows users to watch the line, check alarms and make changes as if they were on-site. And, with the touch of the screen, procedures, documentation and other forms of technical help are available to aid in troubleshooting a problem.

The computer, keeping vigil over any number of UV lines, can help engineers keep their eye on the ball



Display interface of UV system.

by distilling measurements down to what is important and providing instant access when needed.

Conclusion

While UV curing is often a critical part of the production process and an out-of-spec line can produce a large volume of bad product, real-time monitoring has been virtually ignored. This is despite the ready availability of cost-effective products that make online monitoring simple and easy to achieve.

Real-time monitoring combined with the routine use of a traditional belt radiometer work hand-in-hand to provide the quality control and hard data needed to make good parts and

keep a process running within the process specification.

New computer interfaces make real-time monitoring even more powerful by not only providing better data collection and easy-to-interpret displays, but by alerting technicians to problems as they occur—using immediate text and e-mail notification. This allows even a small operation to have constant control over their critical processes any time of the day or night.

—Paul Mills is a consultant and Jim Raymont is director of sales, EIT LLC, Sterling, Va.