Curing of Printing Inks by UV

By Jim Raymont

The use of ultraviolet (UV) energy is what differentiates UV-cured inks from water or solvent-based inks. While a UV ink is "dry" to the touch after it has been properly exposed to UV, the actual "drying" mechanism is one of polymerization and not the evaporation of water or a solvent. A more detailed description of the actual cure mechanism(s) and a comparison between UV inks (or coatings, adhesives and resins) and other technologies will need to be left to chemists and formulators. This article intends to cover some of the key points associated with the curing of printing inks by UV and will not go into a comparison of UV versus other types of ink formulations. While this article uses "inks," many of the same principles apply to coatings, adhesives and resins that are UV coated. Using the word **"CURE,"** we can identify key points for each of the four letters in the word.

Different variables, almost all of which can be tracked, measured and controlled have to line up for the UV process to consistently work at levels that produce quality products and profits.

For the letter "C":

1. Consistency
2. Communication and Cooperation
3. Chemical Reaction

For the letter "U":

1. Ultraviolet
2. Understand Terminology and Process Requirements
3. Understand Your UV Measurement Instrument

For the letter "R":

1. Radiometer Readings and Measurement Strategies
2. Regulate Requirements
3. Record

For the letter "E":

1. Enabling, Environment, Efficient, Economical and Energy Savings
2. Education
3. Emerging Technologies

Cure

1. Consistency

The goal of successful companies is to produce good quality items that can be sold at a profit. Successful companies also minimize scrap or product that cannot be sold. To achieve and maintain quality and profit, production costs, time, throughput and materials all need to be established, measured, monitored and maintained at certain levels. A thorough understanding of your equipment and process is essential. Operating your UV process in a "zone" or "window" where it works best will optimize production and reduce waste, saving your company time and money. Different variables—almost all of which can be tracked, measured and controlled—have to line up for the UV process to consistently work at levels that produce quality products and profits.

2. Communication and Cooperation

Involve all of your suppliers (formulator, substrate, UV source, application equipment, UV measurement, end-user or your customer, if applicable) early in the process and not just when you have a problem. Communication and cooperation between all parties involved is preferred to finger pointing and shoulder shrugging that can happen over time when something changes in your UV process. The majority of the time it is not a "bad batch of ink" or a "bad bulb" that is the reason (excuse) for why you are not curing, but instead something with the process has changed internally at your facility.

This communication and cooperation should start before you are in production—while you are testing, qualifying and establishing your process and process targets. Your formulator should be able to supply you with some general "starting" targets for the curing of a particular ink. These numbers will more than likely have to be adjusted for your equipment and process. To maintain process control once you have your target numbers, there are several variables that you need to monitor, maintain and document.

Decide as a company on how you will communicate within your building, with other company facilities and with your suppliers. Make sure that everyone communicates in the same language and clearly identifies units on radiometer values and the instrument which made the reading.

Examples of communication and specifying radiometer numbers:

- Specify units in measurement to avoid confusion
- 300 mJ/cm^2 *Start*
- 300 mJ/cm^2 UVA (Specify Bandwidth) *Improvement*
- 300 mJ/cm^2 -UVA EIT 320-390nm (Specify bandwidth—both letter and nanometer range, and manufacturer of instrument) *Best*

3. Chemical Reaction

UV curing uses chemicals. Work with your suppliers to understand the requirements for the safe handling, storage and proper disposal of any used/unused products. Examples include the return of used UV bulbs to the manufacturer and/or the disposal of inks that you may not need anymore. Incorporate these requirements into your procedures and training.

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1. Ultraviolet (UV)

As with chemicals, users of UV need to understand the requirements for safely working around a UV source. This includes leaving manufacturers' safety guards in place and using eye and skin protection as required. Care should also be exercised before working on your equipment to make sure the electrical power has been tagged and locked off so that it cannot be accidentally turned back on while someone is working on the equipment.

The UV portion of the electromagnetic spectrum includes wavelengths from approximately 100 to 400 nanometers (nm). The spectral output of the UV system must be matched to the process and the chemistry. There are many types of bulbs available. The type of bulb used will depend on the formulation, equipment, type of process and desired results. Visible light uses color names (red, orange, yellow, etc.) to identify spectral ranges. UV also has spectral ranges and these are identified by letters (A, B and C). See Figure 1.

UVA: 315-400 nm The UVA bandwidth contains the long UV wavelengths. Mercury-type UV bulbs contain a major band of UV energy at 365 nm. Most inks are formulated to respond to UVA.
UVA provides adhesion of the ink to the substrate.

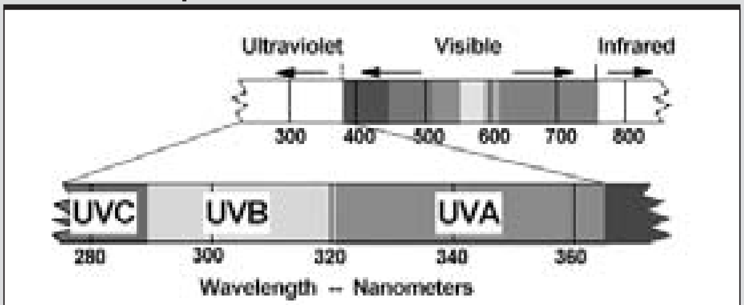
UVB: 280-315 nm The UVB bandwidth assists with the curing of ink and provides toughness to the ink.

UVC: 200-280 nm The UVC bandwidth contains the short UV wavelengths. The majority of UVC energy in this bandwidth is located in the 220-260 nm regions. UVC is important for surface cure and determining the texture, stain, chemical and scratch resistance of an ink.

UVV 400-450 nm The UVV (UV-visible) bandwidth contains the ultralong UV wavelengths. There is no precisely defined boundary between UV and visible light, and the boundary is considered between 400 and 450 nm. UVV is an important bandwidth because, on a relative basis, it has the ability to better penetrate through

Figure 1

Ultraviolet Spectrum



inks, especially those that contain titanium dioxide. Additive (mercury-gallium or mercury-iron) bulbs, which are rich in longer wavelengths, are often used for opaque inks where adhesion or depth-of-cure to the substrate is a problem. The additive bulbs must be matched to the formulation and UV system.

System manufacturers can tell you what type of bulbs your UV equipment can use. Bulb types are not always interchangeable. Have a system in place at your facility to make sure that you have the correct bulb for your process. Buy your UV bulbs based on value (stability, consistency, effective useful UV output over time) instead of the lowest dollar cost per unit.

2. Understand Terminology and Process Requirements

RadTech International North America has produced a *Glossary of Terms for UV Curing Process Design and Measurement*. The glossary is posted on the RadTech Web site at *www.radtech.org.* This can help users and suppliers communicate in a common language when it comes to UV measurement and process control.

Irradiance is the radiant power arriving at a surface per unit area. With UV curing, the surface is most often the substrate and a square centimeter is the unit area. Irradiance is expressed in units of watts or milliwatts per square centimeter (W/cm^2 or mW/cm^2). Irradiance better describes the concept of UV arriving at a two-dimensional substrate than the word intensity which is sometimes also used. UV irradiance is important in your process because it provides the power or "punch" to:

- Penetrate through opaque and pigmented coatings.
- Give depth-of-cure and adhesion to the substrate.

Radiant Energy Density is the energy arriving at a surface-per-unit area (cm^2) with joules or millijoules per square centimeter (J/cm^2 or mJ/cm^2) used as the units. The radiant energy density is the time integration of the irradiance with one watt for one second equaling one joule. In an exposure where the irradiance value is constant over time (square profile exposure), the radiant energy density could be estimated from this relationship. Most exposures in UV curing have the product move into an intense UV area and then out as it exits the UV system. The profiles with moving exposures are not "square profiles." To determine the radiant energy density in a moving exposure, the radiometer calculates the "area" under the irradiance curve. In UV curing, the term "dose" has commonly been used to describe radiant energy density. The radiant energy density is important for total and complete UV cure.

Establishing and documenting process control takes work. The best time to do it is when you are defining the process and working with your suppliers. The next best time is when the process is up and running. The worst time to document your process is when it is not working and curing is not taking place.

If you are trying to find minimum UV values, run tests in which you gradually increase the line speed until you produce an undercure situation. Document this failure point by recording the parameters—irradiance, radiant energy density, power applied to the system and line speed. I suggest building a cushion or caution zone of approximately 20% on your process window that allows for slight changes during a production run (see Figure 2).

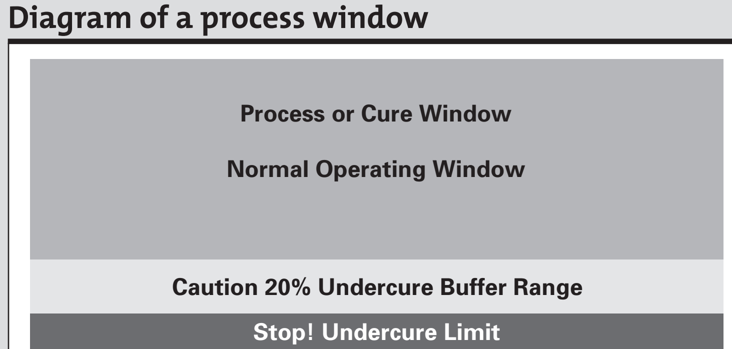
3. Understand Your UV Measurement Instrument

Expectations of UV measurement instruments often exceed their actual performance. Users expect overall performance to be within a small fraction of a percent. Errors introduced with collection techniques can also lead to perceived problems with the instrument. It is important to understand and use your instrument properly, and also use data collection techniques consistent with the instrument and instrument design. Work with the manufacturer of the instrument. Why do readings differ between instruments? What are some of the things to keep in mind when making and comparing readings from different UV measurement instruments?

Bandwidth Variation: Manufacturers have different spectral bandwidths

Figure 2

Diagram of a process window



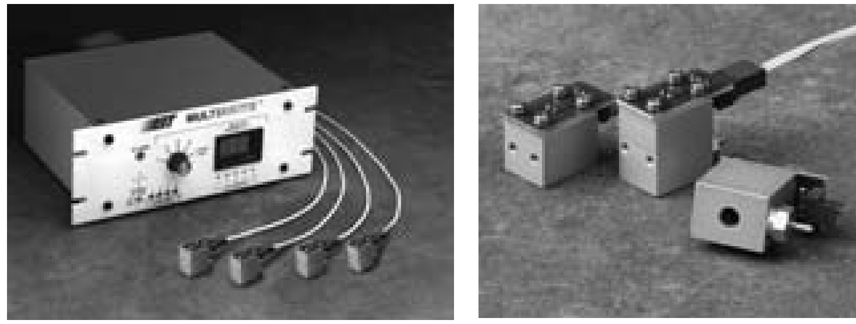
and spectral responses in their instruments. It is often hard to directly compare instruments because of these differences. Some instruments are classified as narrow band while others are broadband instruments. R.W. Stowe of Fusion UV Systems advocates adding identifying information to numbers. Instead of just reporting 900 J/cm^2, report 900 mJ/cm^2 (EIT UVA) or 900 mJ/cm^2 (320-390 nm) to avoid misunderstandings.

Data Collection Speeds: For repeatable, reliable results, a UV instrument needs to collect an adequate number of samples. Newer radiometers sample much faster than previous radiometers. If you see fluctuations in the irradiance values, try collecting your data at either a slower speed or increase the sampling rate on the instrument, if this is possible.

Temperature: Long, slow repetitive measurements with an instrument on high power UV sources can cause the readings to vary slightly. A good common sense rule is that if the instrument is too hot to touch, it is probably too hot to take an accurate measurement.

Calibration Sources: Calibrating an instrument to one type of spectral source (mercury) and then using it under a second source (mercury-additive bulb) can lead to small differences in the readings. If you will consistently use the radiometer under a specific lamp source, ask the manufacturer to calibrate the instrument under that type of source.

Instrument Ranges: What kind of results would you expect to get weighing a baby on a scale designed to weigh trucks? Probably not too good because the truck scale has a dynamic range set up for large objects. Make sure the dynamic range of your UV instrument matches the irradiance levels of your system. Too often, people try to measure very small amounts of UV with an instrument designed to measure high power sources. The instrument may register a reading, but it may be out of the ideal range for which it was designed.



Two examples of relative sensors.

Spatial Response: The spatial response of an instrument describes how the instrument handles light coming from different angles and is measured by the optics in the unit. Most instruments try to approximate a cosine response in their optics.

Electronics: Differences in the electronics between instruments can cause one instrument to reach threshold and start counting UV while another instrument needs a higher irradiance value to reach threshold and count.

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1. Radiometer Readings and Measurement Strategies

In order to measure UV, an instrument or sensor has to be exposed to the UV in your system. Instruments and sensors can be passed through, inserted into or mounted permanently into the UV system. Instruments and sensors can provide either absolute or relative numbers.

Absolute Instruments: These are instruments calibrated against a standard. For UV-curing applications, absolute instruments most often report Watts/cm^2 or Joules/cm^2 for the spectral bandwidth(s) of the instrument. A radiometer can report the highest irradiance measured (peak irradiance) and/or a profile of the irradiance over time (irradiance profile). Absolute reading instruments allow comparison between different UV systems, different locations and between suppliers and customers (for example, a coating formulator and user of the material).

Relative Instruments: Relative instruments provide feedback to the user on the "relative" intensity of UV reaching the sensor. A display, monitor or output signal is adjusted (often to 100%) when conditions are ideal (clean reflector, new bulb). The display will change as the relative intensity of the UV changes. Relative monitors are good for measuring UV on systems where the process window is small; where an absolute radiometer cannot be passed through or inserted into the system; or where continuous feedback of the process is needed.

2. Regulate Requirements

There are other variables beyond the irradiance and radiant energy density values (Watts/cm^2/Joules/cm^2) that you need to document, monitor and measure in your process and equipment. Consider tracking the following:

Line Speed/Dwell Time: The line speed/dwell time is important because it controls the amount of time that your product is exposed to UV. Faster speeds mean less exposure time to UV and slower speeds mean more exposure to UV. The relationship between line speed and the amount of UV (radiant energy density-Joules/

Figure 3

Line speed variations: changes in the UV output when the process speed is changed

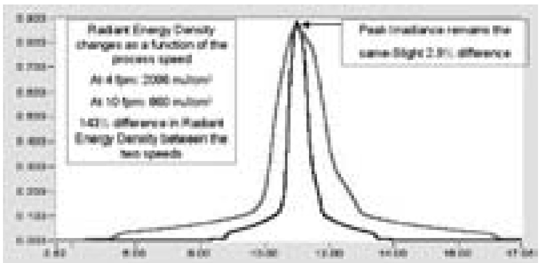
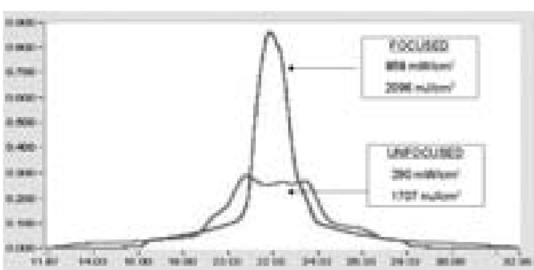


Figure 4

Reflector position: the same lamp and resulting UV in both focused and unfocused positions



The effect of moving the UV housing away from the cure surface

cm²) reaching your substrate is inversely proportional. Doubling the line speed will cut in half the radiant energy density (Figures 3 and 4). Check and confirm your line speed.

Hour Meter: Many UV systems have an hour meter that allows you to track (with a little subtraction) the number of hours on the current bulb in the lamp housing. This number is worth tracking over time, but keep in mind that the information it provides will only give you an estimate of bulb life. The hour meter does not indicate the number of UV system starts and stops, which can be hard on a bulb. The hour meter does not indicate if the bulb has been running hot or cool, or if there is contamination deposited on the bulb's surface.

Amp Meter: Many UV systems have an amp meter that allows you to track incoming electrical power. Keep an eye on the amp meter, especially if you are in an area prone to power fluctuations or if you find that you are close to the minimum amount of UV to cure your product.

Lamp Power: The numbers associated with lamp power are often confused with the amount of UV reaching the surface being cured. Lamp power is the electrical power applied to the UV system. Watts per inch (WPI) or watts per centimeter (WPCM) are the units with values typically between 200 and 600 WPI or 80 and 240 WPCM. The numerical value is calculated by:

$$\frac{\text{Voltage x Amperage (Watts)}}{\text{Arc length of the bulb (inch or cm)}}$$

The WPI/WPCM power applied to the system is not the effective amount of UV generated nor is it the effective amount of UV reaching the cure surface. Effective UV is the UV matched to your chemistry and process, and delivered to the cure surface. The UV energy that reaches the cure surface is usually very small compared to the power applied to the system. A typical 300 WPI (120 WPCM) system may only have 0.5-4 watts per square centimeter (W/cm^2) of effective UV reach the cure surface. The value can vary tremendously between different manufacturers and system types. Do not use the applied power as a measure of effective UV reaching the cure surface. Work with equipment suppliers and measure UV with a radiometer to compare different systems or power settings.

Reflectors: The reflector is one of the workhorses in any UV system (see Figure 4). It is estimated that 60-80% of the energy that reaches the substrate is reflected energy. In order to maximize the amount of UV reaching the cure surface, the reflector has to be properly maintained and kept clean. Dirty reflectors can reduce the irradiance value by more than 50%.

Spectral Output: The spectral output of your UV system must be matched to your process and chemistry. There are many types of bulbs available. The type of bulb that you use will depend on your formulation, equipment, type of process and desired results.

Unique Variables: Evaluate if your process has any unique variables which need additional monitoring.

For each variable, decide how it is going to be monitored or checked, the frequency and who will be responsible.

3. Record

Job, performance or process control logs should be used to track each of your UV systems. It is a central place to keep performance information on the system that can be referred to if things stop working. It can be as simple as a clipboard and log generated with a word processing or spreadsheet program. Track the items (both measurable and non-measurable) that are important for your process.

When things stop working, examine your log.

- Was it a gradual change over time toward the identified caution area or was it a sudden change?
- Any changes to the process, equipment or suppliers?

When things stop curing:

- Confirm key equipment settings and measure the UV.
- Perform UV system maintenance and clean the reflectors; rotate the bulbs, if possible; check cooling and air flow on the housing.
- Measure the UV again, looking for improvement and movement back within the process window.
- Replace UV bulbs or adjust key equipment variables until you are back in your process window.

How often should you monitor and take UV readings? There is no easy answer and you will have to let the information that you collect and your process dictate the frequency of readings.

Remember that UV measurement can't help you unless you document and record the readings!

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1. Enabling, Environmentally Friendly, Efficient, Economical, Energy Saving

The five "E's" listed above were generated by RadTech International North America to describe the advantages of both ultraviolet and electron beam processes. The two other "E's" that I like to include are:

2. Education

To be successful with UV, you need to understand the basic concepts about UV and your process. Documenting and maintaining your process is much easier than hoping that things work out. By reading this article, you are working to increase your knowledge about UV. Look to your suppliers, trade shows, conferences, Web sites, trade organizations and webinars to further increase your UV and process knowledge.

3. Emerging Technologies

The curing of inks with UV continues to evolve. New formulations and equipment make new applications with UV possible. One area of great interest is UV-LEDs that continue to evolve and can be used for many diverse applications, including digital printing. Pay attention to changes and evaluate if they are right for you.

Conclusions

Three key points to remember from this article:

1. Understand your UV equipment and process, and operate in the "zone" where your process will allow you to optimize production, reduce waste and save your company time and money.
2. Measure and track both the UV conditions (irradiance and energy density) as well as the other variables in your process
3. Work and communicate with all suppliers

Remembering to record, review and react to regular radiometer readings results in repeatability and reliability.

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