Life After the Honeymoon: Getting to Know, Understand, Respect and Live with Your UV System and Process

The definition of the word honeymoon is similar in the several dictionaries that I checked. From the Random House Dictionary of the English Language, College Edition:

hon•ey•moon (hun´ē mo͞on ´) n 1. a vacation or trip taken by a newly married couple 2. the month or so following a marriage 3. any new relationship characterized by an initial period of harmony

How does the word honeymoon apply to an article on equipment? When any equipment — not just UV equipment — is first installed, it creates a "new relationship characterized by an initial period of harmony." What causes the honeymoon? Is it the excitement over the new equipment? Attention to detail and maintenance as you learn how to operate and live with the equipment? Support and help from the factory or sales representative to make sure the relationship gets off to a good start? Are you and your maintenance staff also on your best behavior at the start of the relationship?

Depending on your process and equipment, your UV honeymoon period may last anywhere from one month to several months. During this time, life is good! Eventually the moon wanes and you are brought back to reality. The honeymoon abruptly ends the first time your product does not cure. The wake-up call and jump back to reality never happens at a good time — customers and your boss want to know when they will have product. You begin to wonder what you got yourself into and doubt if you really know your UV system. Who is this system with whom I am partnered?

Calls (and sometimes accusations) are made to the equipment, formulator and substrate suppliers. The suppliers come in and help to get your production up and running again. It is at this point that you realize that you have to get to know, understand, respect and learn to live with your UV system if the relationship is to last and be profitable.

Ask anyone who has been in a long lasting, happy relationship what their secret is and many will reply that there is no secret or shortcut to happiness. Their relationship is a product of hard work, communication and trust. The secret to a long, lasting, happy relationship with your UV system is also a matter of hard work, communication and trust. This article is intended to provide you with the basic building blocks to get you past the UV honeymoon phase and increase the

> The secret to a lasting, happy relationship with your UV system is hard work, communication and trust. And if you only remember one thing, remember UV measurement can't help you unless you document and record the readings!

By Jim Raymont, *Director,* EIT Instrument Markets

Terminology Variations

Many of the terms associated with UV curing have been adapted or borrowed from other disciplines. The use and definition of some of the original terms evolved and changed within the UV fraternity when compared to the original meaning. Right or wrong, it became accepted in everyday use. RadTech International North America is working to address some of the variations in terms associated with UV measurement terminology. Look for a UV Measurement Glossary from RadTech shortly to address some of the language variations and encourage communication in a common language that facilitates understanding.

Manufacturers also introduce term variations to describe and market equipment. What do you call the equipment that generates the UV? Is it a UV Dryer, UV Cure Unit, UV Reactor, UV Station, UV Emitter or UV System? Whatever term you use at your company, make sure that everyone understands what you are referring to. For this article, I will use the term UV System to describe the power supply, lamp housing, reflector, bulb, cooling equipment and transport mechanism (conveyor).

Lamp and bulb are two other terms that are used interchangeably and can sometimes lead to confusion if it is not understood what you are referring to. What happens if you ask your maintenance department to change a lamp on a UV system? Does the supervisor replace just the bulb in the housing or is the entire housing assembly including the reflector, housing and bulb replaced?

How do I differentiate a bulb from a lamp? At home, the light-emitting device that sits on my end table is called a lamp. When it no longer emits light, I change the bulb in the lamp. For this article, I will follow the same reasoning and use the term bulb instead of lamp to describe the cylindrical quartz tube placed in the lamp or lamp housing. Different manufacturers go with different terms.

Whether you call it a bulb or a lamp, communicate and use it consistently at your facility and with your suppliers to avoid confusion.

odds that you will enjoy a long-term relationship with your UV system.

The information should be used to educate yourself and your staff members. Keep in mind that your particular combination of chemistry, substrate and equipment as well as your application method may have unique requirements. Some of the "rules of thumb" in this article will have to be validated for your individual process. Use this article to start or to enhance regular communication with your chemistry, substrate and equipment suppliers. They are the experts who are most familiar with your requirements and are in the best position to help you. Many companies, including EIT, offer training and educational programs to educate end users about UV. Seminars are also available at trade shows and conferences.

Also keep in mind what your UV perspective is when reading this article. An analogy that I like to use when trying to explain UV perspective involves four blind people that are led to an object and asked to describe the object. The four come back with answers of rope, snake, tree and fan. How can this be? The "object" in this example was an elephant. The "rope" person had the elephant's tail, the "snake" person the trunk, the "tree" person a leg and the "fan" person an ear. Each answer was based on only one perspective of the elephant. Do we do the same with UV systems and UV curing? Does a formulator have a different perspective on UV curing than a press operator or customer looking for an improved product? What about your accountant's perspective? The sales manager working to sell a customer? The company owner? Keep your own UV perspective in mind as you read the article.

Why Should I Get to Know my UV System and Process?

There are several reasons and ways to describe why I would want to know my process and system. All reasons boil down to being able to save time, save money, deliver consistent products or a combination of all three (see Figure 1). Questions to ask yourself:

- Repeatability: Can I set this job up again and get the same results next week? Next month? How long will it take to set the job up again and duplicate the cure conditions?
- Reliability: How sure am I that the product I am shipping is of the same quality as the last shipment? Will it block together before it gets to the customer? Can I reduce scrap? Increase productivity?
- Documentation: Are ISO procedures or customers pushing me to measure, control and document my process and management system? Do I have the job adequately documented so that I or another person can run it without going through a lengthy trial and error process? How do I handle training? Maintenance procedures?
- Verification: How do I check, control and assure the quality of my product? What tests are used and what criteria do I have to determine pass/fail?
- Maintenance: Wouldn't it be nice to be able to predict and schedule preventative maintenance between jobs instead of during a busy time? How do I pinpoint what piece of equipment needs attention? How do I verify that the work I am doing on the equipment has a positive impact on the system?
- Job Security: When you maintain and cure by numbers instead of by guessing, you reinforce your value as an employee. Even though you work in the graphic arts, you can still apply some basic science to the process.

What can I measure, monitor, document or control on my UV system to establish process control

What can I measure, monitor, document or control on my UV system to establish process control?

For those new to UV, or for those who realize that they need to establish process control, the thinking usually follows this pattern: "If I want to establish control of my UV system, I need to measure UV. To measure UV I need a UV radiometer." It sounds simple and logical, and while measuring UV and the UV radiometer are an important part of the process, it is only part of the picture. Buying a UV radiometer and making UV measurements without testing and documentation will not lead to process control. Waiting for

Belt FPM vs. Belt Revolutions

Conveyor Length (ft): 3.0
Roller Diameter (in): 4.0
Belt Length (ft): 6.4

Formula: $\frac{60 \times \text{Belt Length (ft)}}{\text{Seconds for one revolution}}$ *= Speed (Feet/Minute)*

Secs/Rev	FPM	Secs/Rev	FPM	Secs/Rev	FPM	Secs/rev	FPM	Secs/Rev	FPM
382.8	1	10.6	36	5.4	71	3.6	106	2.7	141
191.4	2	10.3	37	5.3	72	3.6	107	2.7	142
127.6	3	10.1	38	5.2	73	3.5	108	2.7	143
95.7	4	9.8	39	5.2	74	3.5	109	2.7	144
76.6	5	9.6	40	5.1	75	3.5	110	2.6	145
63.8	6	9.3	41	5.0	76	3.4	111	2.6	146
54.7	7	9.1	42	5.0	77	3.4	112	2.6	147
47.9	8	8.9	43	4.9	78	3.4	113	2.6	148
42.5	9	8.7	44	4.8	79	3.4	114	2.6	149
38.3	10	8.5	45	4.8	80	3.3	115	2.6	150
34.8	11	8.3	46	4.7	81	3.3	116	2.5	151
31.9	12	8.1	47	4.7	82	3.3	117	2.5	152
29.4	13	8.0	48	4.6	83	3.2	118	2.5	153
27.3	14	7.8	49	4.6	84	3.2	119	2.5	154
25.5	15	7.7	50	4.5	85	3.2	120	2.5	155
23.9	16	7.5	51	4.5	86	3.2	121	2.5	156
22.5	17	7.4	52	4.4	87	3.1	122	2.4	157
21.3	18	7.2	53	4.4	88	3.1	123	2.4	158
20.1	19	7.1	54	4.3	89	3.1	124	2.4	159
19.1	20	7.0	55	4.3	90	3.1	125	2.4	160
18.2	21	6.8	56	4.2	91	3.0	126	2.4	161
17.4	22	6.7	57	4.2	92	3.0	127	2.4	162
16.6	23	6.6	58	4.1	93	3.0	128	2.3	163
16.0	24	6.5	59	4.1	94	3.0	129	2.3	164
15.3	25	6.4	60	4.0	95	2.9	130	2.3	165
14.7	26	6.3	61	4.0	96	2.9	131	2.3	166
14.2	27	6.2	62	3.9	97	2.9	132	2.3	167
13.7	28	6.1	63	3.9	98	2.9	133	2.3	168
13.2	29	6.0	64	3.9	99	2.9	134	2.3	169
12.8	30	5.9	65	3.8	100	2.8	135	2.3	170
12.3	31	5.8	66	3.8	101	2.8	136	2.2	171
12.0	32	5.7	67	3.8	102	2.8	137	2.2	172
11.6	33	5.6	68	3.7	103	2.8	138	2.2	173
11.3	34	5.5	69	3.7	104	2.8	139	2.2	174
10.9	35	5.5	70	3.6	105	2.7	140	2.2	175
10.6	36	5.4	71	3.6	106	2.7	141	2.2	176

Figure 4: Use of a stopwatch and a chart designed for your system will allow you to confirm the actual process speed. In this chart for the UV system described, if a belt revolution takes 18 seconds, the actual speed is 21 feet per minute (Speed chart developed and used courtesy of UV Systems, Houston, TX).

your ink supplier to take a reading with their UV radiometer every two to three months or having one sit in a locked cabinet in the production manager's office will not establish process control. Waiting until you have a curing problem instead of trying to establish control when things are working is not process control — it is process (and sometimes job) suicide. Talking the "joules and watts talk" will not give you process control unless you also "walk the walk" and understand what the radiometer "numbers" along with several other variables mean to your individual system and process.

To establish process control, there are several variables that you need to monitor, maintain and document in addition to watts and joules. Some of the variables have numbers that can be attached to their

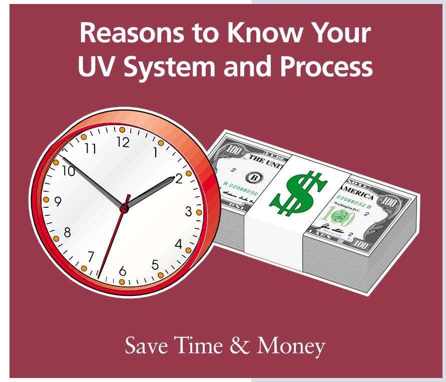


Figure 1: Establishing and maintaining process control will save you time and money.

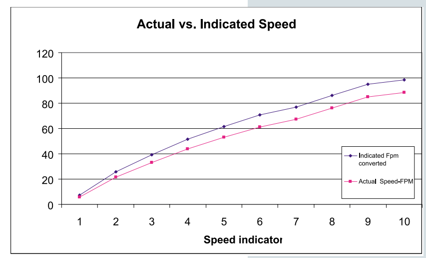
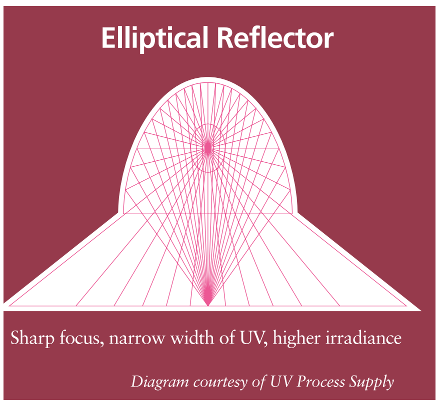


Figure 2: Small variations in the actual versus the indicated process speed are expected. Confirm and document your dwell time independently.

Figure 3: Digital tachometer for measuring belt speed (Photo courtesy of UV Process Supply).

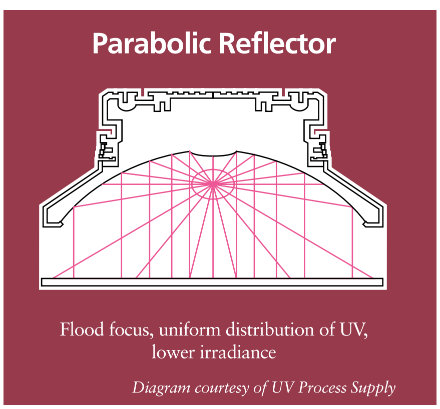
Waiting until you have a **curing problem** instead of trying to establish control when things are working is **not process** control



Sharp focus, narrow width of UV, higher irradiance

Diagram courtesy of UV Process Supply

Figure 5: Typical light pattern from an Elliptical Reflector design.



Flood focus, uniform distribution of UV, lower irradiance

Diagram courtesy of UV Process Supply

Figure 6: Typical light pattern from a Parabolic Reflector design.

values, while others require confirmation that they have not changed over time for a particular set-up. In your process and system you need to look at these variables:

Dwell Time/Belt (Line) Speed

I once asked a customer how fast they run their production line and the answer was, it depends on how much they have scheduled for the day. If we have a lot to do, we run faster than on a slow day. Running fast gets the substrate through the UV system, but have you produced good quality products?

In graphics applications using conveyors, the UV dwell time is most often expressed as a belt/line speed in feet (or meters) per minute. In some applications the product is static and the UV source moves over the product. Dwell time in this example would be controlled by the speed of the moving UV source instead of by the conveyor speed. In both cases above, the substrate would be exposed to ramp up, a peak and a ramp down of the UV irradiance. UV applications (plate/screen exposures, spotcure, flood) controlled by timers, shutters or a combination of both generally exhibit a more uniform irradiance profile.

The dwell time/belt speed is important because it controls the amount of time that your product is exposed to UV. Faster belt speeds mean less UV, slower speeds mean more UV. The relationship between belt speed and the amount of UV (radiant energy density — Joules/cm²) reaching your substrate is inversely proportional. Doubling the line speed will cut in half the radiant energy density or dose.

This inverse relationship between radiant energy density and belt speed allows UV measurements to be made at slower belt speeds and extrapolated out to faster production speeds. Taking readings at slower belt speeds is preferred because it ensures that the radiometer collects an adequate number of samples in the peak area of UV.

Belt/line speeds need to be checked independently of displays or indicators on your system. A motor speed controller may be calibrated at one or two points along its scale. It is generally very accurate at these calibration points. The speed controller calibration may not be linear and the further away from a calibration point that you move, the greater the chance for variation. Variations of 20-25% when comparing indicated speed to actual are not uncommon. Moving from dial setting "two" to setting "four" does not automatically double belt speed (see Figure 2).

It is a good idea to check each of your systems to see how the indicated speed compares to the actual speed. There are two options for day-to-day production monitoring. The first is to use a small speed tachometer. A small wheel on the tachometer is placed against the conveyor belt and the actual speed in feet or meters per minute is displayed (see Figure 3).

A less expensive option, developed by Ultraviolet Systems (Houston, TX) involves the use of a stopwatch and speed chart (Figure 4) that you develop for each of your systems. The user measures the time in seconds that it takes for the belt to make one revolution on their conveyor. Using the time in seconds, the actual speed can be found on a chart that you have set up for the belt length on your system. The formula converts this time to a speed:

$$\frac{60 \text{ X Belt Length (FT)}}{\text{Seconds for one revolution}} = \text{Speed (Feet/Minute)}$$

Proper tracking and documentation of the dwell time/belt speed will allow you to make adjustments in this variable as needed to maintain control of your process.

Hour Meter

Most 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. Keep in mind, however, 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.

Comparing UV radiometer readings to hour meter readings will help you to identify trends in performance of your current bulbs and system. How many hours can I expect with the brand of bulbs I am currently using? Is the performance stable over 500 hours? 1000 hours? Longer? Can I expect performance to drop off at a certain point, which will require me to make adjustments to compensate for the drop? Can I extend the useful life of the bulb with system adjustments? Does the bulb live up to the claims of the manufacturer? Is Purchasing department buying bulbs at the lowest price or best value? Does a bulb that costs more initially give me better, more stable and longer lasting useful performance in my system? Do I have the numbers to convince manage-

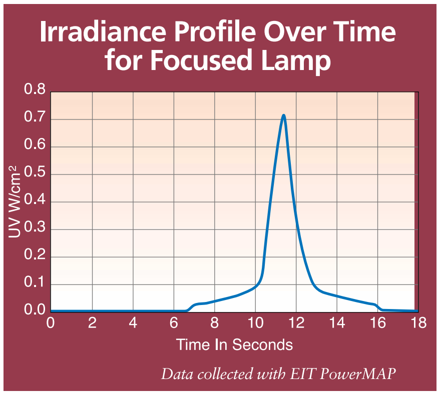


Figure 7: Clearly defined profile shape from a focused lamp, often produces higher irradiance values.

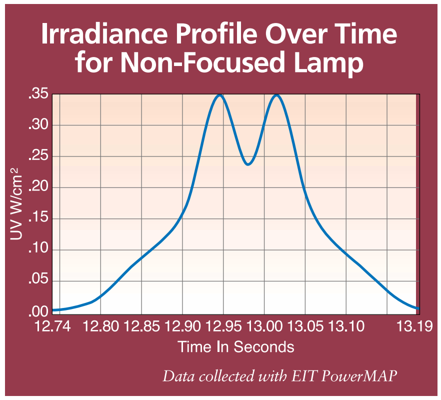


Figure 8: Typical light pattern from lamp that is out of focus. It is important to confirm if your process and equipment was designed to run out of focus or if the out of focus condition is a change due to a bulb sagging or lack of maintenance.

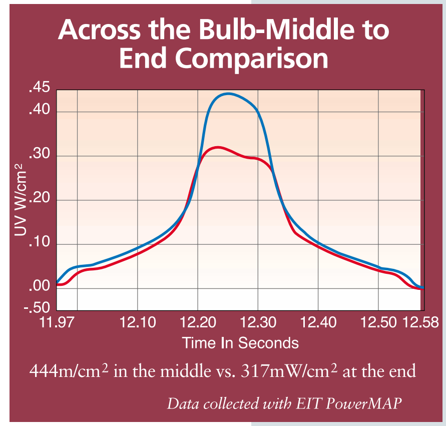


Figure 9: Comparison of measurements at the end of the bulb, versus near the middle. If the readings are lower in the middle than on the end, opposite of what is shown here, check the positioning of the bulb and look for sag.

ment to invest in a particular brand bulb for my system?

Amp Meter

Most UV systems have an amp meter that allows you to track incoming electrical power. Under normal conditions, the incoming electrical power may vary by as much as 20 percent. During times of heavy demand (hot days) or reduced/limited supply (California) this variation could be even greater. Are you in a business park where everyone starts equipment at the same time on Monday morning? What about other high draw equipment located in your facility? Will a drop in incoming power reduce the amount of UV reaching your substrate to a point where your product is no longer curing? My suggestion is to 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 substrate. Lamp power is the power applied to the UV system. The unit most often used to describe lamp power is watts per inch (WPI). (Watts per centimeter in the metric system-WPCM.) It is common to hear systems described as having 150-600 WPI of power, with a few manufacturers pushing even higher. WPI is calculated by:

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

The WPI number is an estimate and can vary from the true power applied in a system. The efficiency of the power supply as well as a "power factor" figure into the calculations. Many times the applied power is changed in steps (150-200-300 WPI) and the steps may not be linear. The calculated WPI from a manufacturer may or may not include the power factor adjustment for the power supply. The power factor is a measure of efficiency of the system and typically runs between 0.90 and 0.93. This further reduces the estimated WPI of the system.

For a 16-inch system with 240 volts, 20 amps and power factor of 0.90, the calculated WPI rating of the system would be estimated at 270 WPI.

$$\frac{\text{240 Volts x 20 Amps (Watts)}}{\text{16 inches Arc Length}} \text{ x 0.90 Power Factor = 270 WPI}$$

For Watts per centimeter on the same system:

$$\frac{\text{240 Volts x 20 Amps (Watts)}}{\text{40.6 cm Arc Length}} \text{ x 0.90 Power Factor = 106 WPCM}$$

The WPI 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.) Most of the energy applied to the system generates visible and infrared radiation. The UV energy that reaches the cure surface is quite small when compared to the power applied to the system. *A typical 300 WPI system may only have 1-4 watts per square centimeter (W/cm^2) of effective UV reach the cure surface.*

On a UV system, as the power within a system is increased, the amount of UV reaching the cure surface generally increases. Switching from 200 WPI to 400 WPI does not automatically mean that the UV reaching the substrate will double. The amount of UV that reaches the cure surface has to be measured and documented with a radiometer as changes are made to the lamp power.

Determine where the power setting should be for each job and double check it before and during the job. Is the power switch in a location where it can accidentally get bumped? As bulbs age, you may be able to increase their UV output by increasing the power that you apply. Pushed to run faster? Increasing the power applied to the UV system may allow you to increase your production speed. Do it with numbers instead of by guessing.

The amount of UV reaching the cure surface from two different manufacturer's systems, set at the same lamp power number can vary widely. It is important to equally compare equipment and make sure that any new system you are considering can provide you with the UV output that you need for your process. Involve your suppliers in any UV system tests.

Figure 10: Yellow tape attached to the UV system to guide product placement on the UV conveyor (Photo courtesy of Avery Dennison).

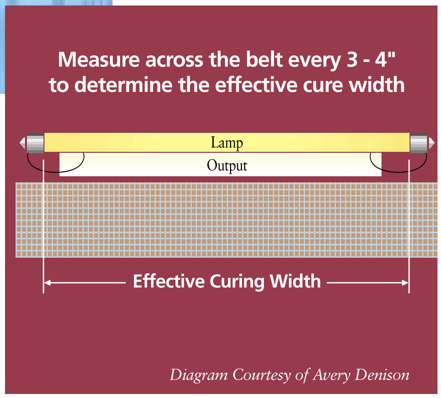


Figure 11: Procedure to find the effective cure width with your radiometer (Courtesy of Avery Dennison).

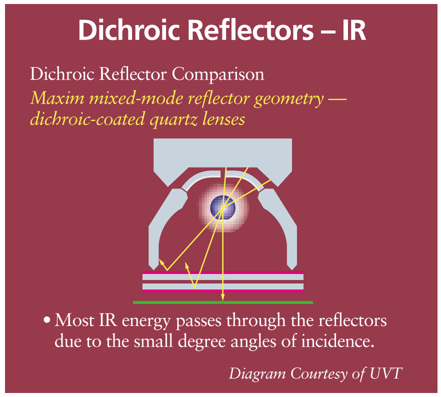


Figure 12: IR energy reaching the substrate is minimized through the use of dichroic reflectors (Courtesy of UV Technology).

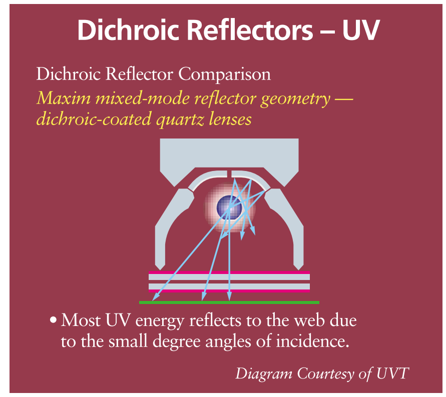


Figure 13: UV energy is reflected to the substrate while the amount of IR is minimized (Courtesy of UV Technology).

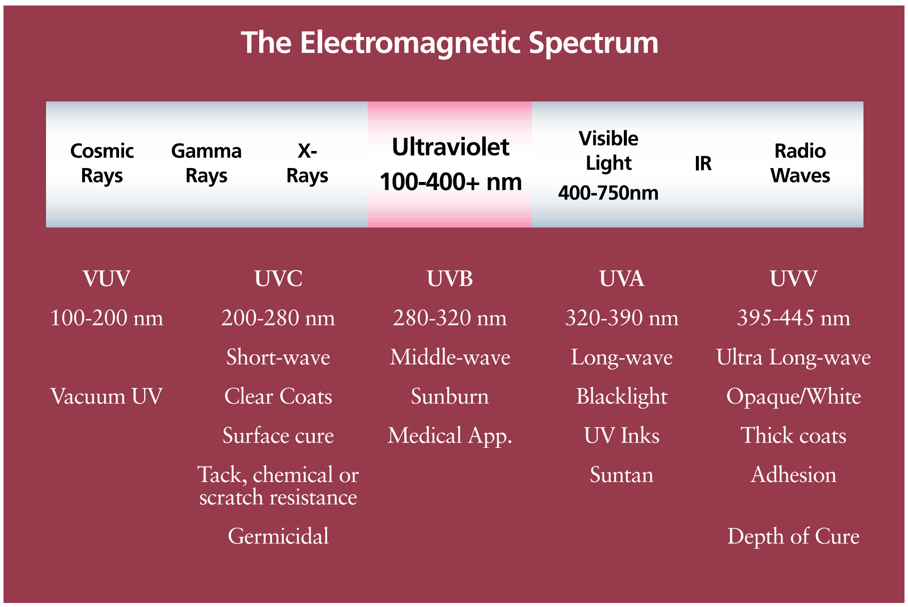


Figure 14: Summary of the major wavelength ranges within the UV portion of the electromagnetic spectrum.

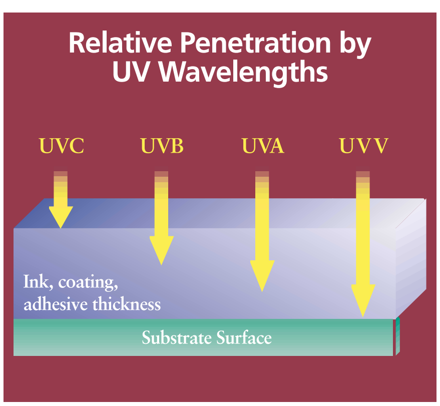


Figure 15: The longer wavelengths have a better chance for penetrating through coatings than the shorter wavelengths.

Power Supply

The power supply is not something that you normally monitor on a day-to-day basis for process control. Follow the manufacturer's directions for maintenance, installation and power feed requirements. Be aware that there are several types of power supplies available and they are not always interchangeable. Some power supplies may limit the types of bulbs (additive) that you can use in your system. Conventional, Magnetic, Solid State, SCR, Stepped, Variable Power and High Fre-quency are some of the terms that you may encounter when discussing power supplies. Work with your suppliers to determine the best power supply for your UV equipment and application if you are looking at new equipment or replacing an existing power supply.

Reflectors

The reflector is one of the workhorses in any UV system. 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. The information that you record and track on your system will give you clues as to when the reflector(s) need to be cleaned. Follow the recommendations of the manufacturer to clean the reflectors (often it is isopropyl alcohol and a lint free cloth). Stay away from anything that will damage the reflector's surface. I suggest a "measure, clean, rotate, reassemble and measure" procedure when cleaning the reflectors. Measure the system with your radio-meter, clean the reflectors, rotate the UV bulb if possible, reassemble the system and take another measurement, looking for improvement.

Most UV systems use either an elliptical or parabolic design (see Figures 5 & 6). The elliptical design, which is probably more common in the graphics applications, offers a focused narrow width of UV and generally produces higher irradiance (intensity) values. The parabolic design has more uniform distribution of UV and generally produces lower irradiance values. Each reflector design has its applications. The reflector that is best for your system depends on the application.

The position and diameter of the bulb in the reflector, the shape and material of the reflector, distance to the substrate, pattern of light on the substrate (focused, non focused) and cooling mechanisms (air flow, water cooled, heat sinks) are all carefully evaluated when designing a system (see Figures 7 & 8). It is important to maintain the systems as designed.

On UV systems over 36-48” in width, there is a tendency for the middle of the UV bulb to sag slightly over time. This slight sag can alter the design and reflective geometries in the system.

Less UV is delivered to the substrate when the UV bulb sags. The potential for bulbs to sag is the reason to rotate the UV Bulb when cleaning the reflector. On wide systems, it is important to measure in several places across the width of the conveyor (see Figure 9, 10 & 11). It is also important to measure and document if the UV drops off near the edge of the conveyor.

The infrared energy that is produced in a UV housing often helps with the UV chemical reaction. Some substrates such as films do not tolerate excessive amounts of IR energy well. Equipment manufacturers have ways to selectively filter out infrared energy while allowing the UV to reach the substrate. Changes are most often made to the reflector material (dichroic) or design of the system (see Figure 12 & 13). Changes or substitutions in the reflector material can result in changes where your process no longer works.

The key to maintaining process control in production from the reflector standpoint is to monitor and properly maintain (keep it clean) the original design conditions and characteristics. If your process has been designed to use an elliptical reflector that focuses UV on the substrate, maintain the system that way.

Spectral Output

Where are we measuring? In the UV system! What part of the electromagnetic spectrum? The UV part! We need to be more specific about where in the UV spectrum we are measuring for two reasons:

1. Within the UV portion of the electromagnetic spectrum, different wavelengths of UV produce different results. The source of your UV should be optimized to produce the desired results.

2. Formulations contain photo initiators that react when exposed to the specific portion of the UV spectrum. In other words, your chemistry has to reach out and do a handshake with the UV energy from your system. If the chemistry is not matched to the UV energy, then the results will not be ideal.

The UV portion of the electromagnetic spectrum includes wavelengths from approximately 100 to 400-450 nanometers. (One nanometer equals 1/1,000,000,000 of a meter (10-9) and is abbreviated nm.) Four to five wavelength ranges are generally designated in the UV area of the electromagnetic spectrum (See figure 14). The UV wavelength range names were originally used to describe the physiological effects of UV. The boundaries are not cast in stone but the generally accepted boundaries are:

1. VUV: 100-200 nm Vacuum UV contains the shortest wavelengths in the UV portion of the spectrum. They do not transmit in air, only in a vacuum. While important to scientists looking at UV radiation in space, Vacuum UV is not normally measured in graphics applications because it does not transmit in air. VUV should not be confused with the portion of UV bordering on the visible light portion of the spectrum that is sometimes referred to as UVV.

2. UVC: 200-280 nm The UVC bandwidth contains the short UV wavelengths. The majority of UVC energy in this bandwidth is located in the 222-254 nm regions. UVC is important for surface cure and determining the texture, stain, chemical and scratch resistance of a coating. UVC (254 nm) is also used for germicidal treatment of air and water. The UVC- (254nm) does not “kill” an organism such as bacteria, but instead inactivates it through alteration of the DNA. The inactivated organism is not able to reproduce.

3. UVB: 280-315 nm The UVB bandwidth can assist with the curing of inks and coatings if a UVB responsive photo initiator is present in the formulation. UVB is probably best known for the effects it can have on human skin. Most commercial sun blocks used to prevent sunburn will state that they protect against “UVB”. In controlled exposures, UVB can be used for medical phototherapy.

4. UVA: 315-400 nm The UVA bandwidth contains the long UV wavelengths. Mercury type UV bulbs contain a major band of energy at 365 nm. Most inks and coatings are formulated to respond to UVA. If you are using mercury bulbs without any additives, your formulation is

If your power supply is a **variable** type, the spectral output of the bulb may also vary from the **extremely low** to high power settings

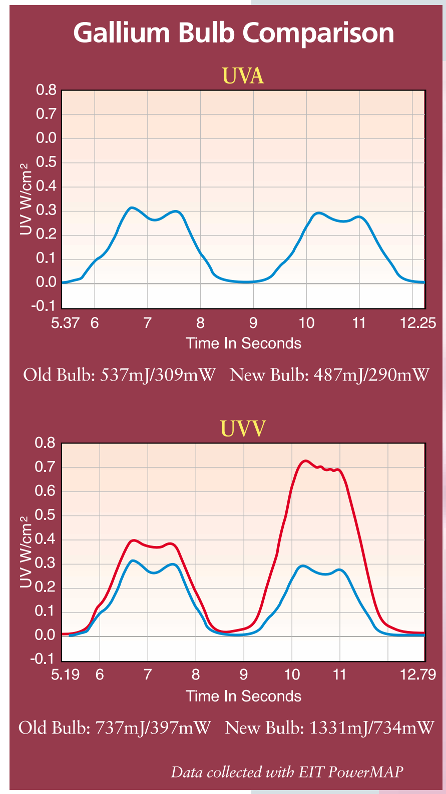


Figure 16: Looking at only the UVA, the old and new bulbs appear to be similar in output. There is quite a difference in the output of UVV with the new bulb significantly. It is important to sometimes measure more than a single UV bandwidth. (Information originally collected by Efsen Engineering).

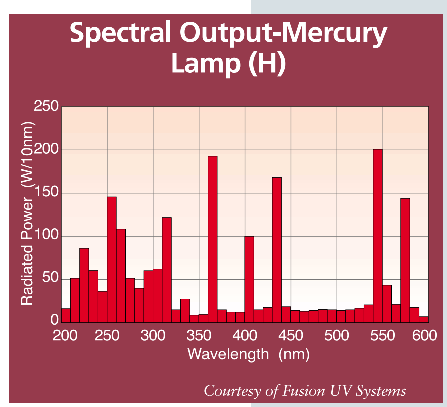


Figure 17: Typical Spectral output from a Mercury Lamp (Courtesy of Fusion UV Systems).

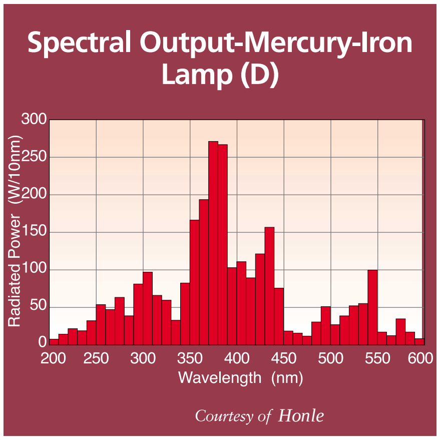


Figure 18: Typical Spectral output from a Mercury-Iron Lamp (Courtesy of Honle).

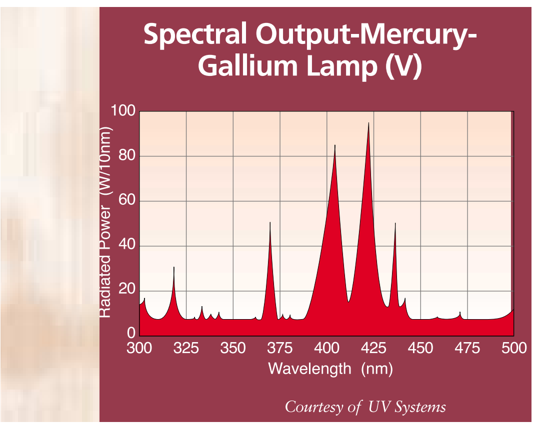


Figure 19: Typical Spectral output from a Mercury Gallium Lamp (Courtesy of UV Systems).

In the real world, UV systems are often purchased first or an older existing system is adapted to a new process

probably responding to UVA. UVA can also tan the skin and most sun blocks and lotions will also protect against UVA.

5. UVV 400-450 nm The UVV bandwidth contains the ultra long UV wavelengths. There is no precisely defined boundary between UV and Visible Light, and the boundary is considered between 400-450 nm. The final "V" in UVV refers to the visible and it should not be confused with the "V" as in vacuum in VUV. UVV is an important bandwidth because on a relative basis it has the ability to penetrate through inks and coatings much better than shorter UV wavelengths. Additive (mercury-gallium or mercury-iron) bulbs, which are rich in longer wavelengths, are often used for opaque inks and coatings where adhesion or depth of cure to the substrate is a problem. The additive bulbs must be matched to the formulation and UV system. (see Figure 15)

The spectral output of your UV system must be matched to your process and chemistry (see Figure 17, 18, 19). There are many types of bulbs available. The type of bulb that you use will depend on your formulation, type of process and desired results. It is normal to expect small variations in the bulb over time as it ages. The shorter UVC wavelengths usually drop out first in mercury bulbs. Some of the enhanced longer (UVV) wavelengths found in additive bulbs may also diminish as the bulb ages. If your power supply is a variable or step-less type, the spectral output of the bulb may also vary from the extremely low to high power settings. Check with your UV equipment supplier. The spectral output may also shift based on the diameter of the bulb, type of bulb envelope (ozone producing, ozone free) and with changes in the cooling or airflow in the lamp housing.

Each system manufacturer can tell you what types of bulbs your system can use. Bulbs are not always interchangeable and some older UV systems may not have a power supply "kicker" to ignite additive (mercury-gallium, mercury-iron) bulbs. Buy your UV bulbs on value (stability, consistency, effective useful UV output over time) instead of the lowest dollar cost per unit.

Unique Application, Formulation and Substrate Variables

Evaluate if your process has any unique variable that needs additional monitoring. Examples include:

- Inert curing where you are flushing the lamp housing with nitrogen to reduce oxygen
- External process variations where the substrate, formulation or facility experiences wide swings in temperature, humidity, static, handling or storage conditions

Metric System Prefixes

- The 'milli' prefix as in millijoule is equal to 1/1,000 (10^{-3}) of the base unit and is abbreviated by the letter "m". Examples: 2387 mJ/cm² = 2.387 J/cm² or 789 mW/cm² = 0.789 W/cm²
- The 'micro' prefix as in microwatt is equal to 1/1,000,000 (10^{-6}) of the base unit and is abbreviated by the symbol "m". Example: 562 mW/cm² = 0.562 mW/cm² = 0.000562 W/cm²
- The 'nano' prefix as in nanometer is equal to 1/1,000,000,000 (10^{-9}) of the base unit and is abbreviated by the symbol "n". Usage: The EIT UVA bandwidth measures UV between 320-390 nm.

UV Measurment

For each variable we have covered that is related to UV process control (Dwell Time/Belt Speed, Hour Meter, Amp Meter, Lamp Power, Power Supply, Reflectors, Spectral Output and Unique Application, Formulation and Substrate Variables), decide how each variable is going to be monitored or checked and who will be responsible. Then start monitoring and checking the variables. After tracking the information for several months, decide if you can measure some of the variables less frequently. If your system is stable, it is much easier to reduce the frequency of measurement of a few variables instead of trying to figure out what is going on when things are not curing.

Radiation

Radiation is a broad concept and generally relates to any energy that is traveling from one place to another at a speed approximating that of light. The light that you are reading this article by is visible radiation. Your oven at home uses infrared radiation. In the case of UV curing, we are using the UV radiation in the electromagnetic spectrum. Radiation also comes in the form of gamma rays, x-rays and radio waves. Some types, but not all are associated with radioactivity.

When it comes to UV measurement, the irradiance and radiant energy density values in your UV system need to be established, monitored and documented.

To differentiate the two terms, I use a snowstorm analogy. If you are reading this in Florida, substitute rain. Imagine looking out of a window at any point during the snowstorm. The snow could be falling lightly or falling heavily. The rate of snow coming down is analogous to the UV irradiance. How long does the snowstorm last? One hour? One day? The accumulation on the ground is a function of storm length and how heavily the snow was coming down. The accumulation is analogous to the radiant energy density.

Glossary of UV Measurement Terms from RadTech

The UV Measurement Focus group of RadTech has been developing a glossary of terms. Visit the SGIA website at <www.sgia.org/journal/uvglossary.html> We are trying to make everyone aware of the terms associated with UV Measurement so that we are all speaking the same language or at least can understand each other.

Irradiance

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).

In UV curing, the term "intensity" is also commonly used to describe irradiance. Irradiance more correctly describes the concept of UV arriving at a two-dimensional substrate. Habits are hard to break and many people continue to use the word intensity when it applies to UV curing.

Radiant Energy Density

Radiant energy density is the *energy* arriving at a surface per unit area. A square centimeter is again the unit area and radiant energy density is expressed in units of joules or millijoules per square centimeter (J/cm^2 or mJ/cm^2). The radiant energy density is the time integration of the irradiance. In an exposure where the irradiance value is constant over time (square profile exposure), the radiant energy density could be estimated from the relationship of one watt for one second = one joule. Most exposures in UV curing and especially in graphics applications where the product is moving are not "square profiles." The product moves into the UV system, into the area of increasing UV, through the peak UV irradiance area and then exits through a decreasing area of UV irradiance. To determine the radiant energy density in this type of profile, the area under the irradiance curve needs to be measured and calculated

In UV curing, the term "dose" is also commonly used to describe radiant energy density.

Irradiance and Radiant Energy Density Discussion

In an ideal world, your UV system would be matched to your formulation. Testing involving the formulator, substrate supplier, equipment supplier and UV system supplier would be coordinated and the equipment and chemistry matched to each other. The UV system would actually be one of the last items purchased and it would match or exceed the requirements of the process.

In the real world, UV systems are often purchased first or an older existing system is adapted to a new process. One of the important considerations when adapting a UV system to a process is whether or not it has a high enough UV irradiance to not only perform the job, but to do it at a production speed that makes economic sense. Formulations can sometimes be "tweaked" to work with UV systems with low irradiance values but the formulations may cost more or not be able to produce the desired results.

UV arriving at the substrate surface is reflected, absorbed, scattered and transmitted through the coating or ink to the substrate. If coating thickness is the same, it is generally easier to cure a clear UV varnish than an opaque color because the UV is more easily transmitted throughout the clear coating. With a clear coating, it is not unusual for the majority of UV light striking the top surface to penetrate through the coating and be available for reacting with the coating at the substrate level. With an opaque color, only a small percentage of the UV striking the surface will reach the substrate level. Increasing the coating thickness will dramatically reduce the amount of UV that reaches the substrate (See Figure 20).

UV irradiance is important in your process because it provides the "punch" to:

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

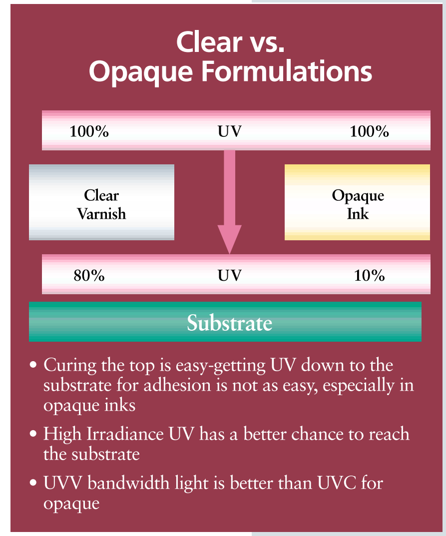


Figure 20: There are differences when curing clear and opaque coatings. Work with your suppliers to understand and establish the amount and type of UV needed for your coatings.

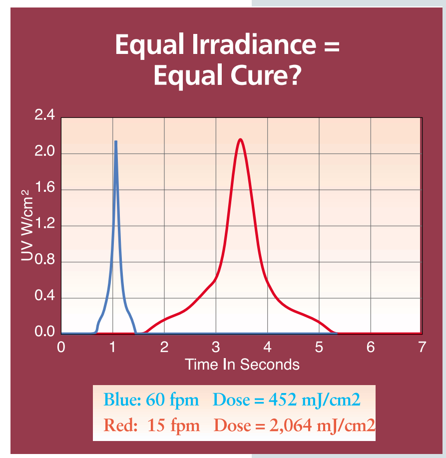


Figure 21: Equal numbers of Watts do not always lead to equal cure characteristics. It is important to establish and maintain energy density levels for your process.

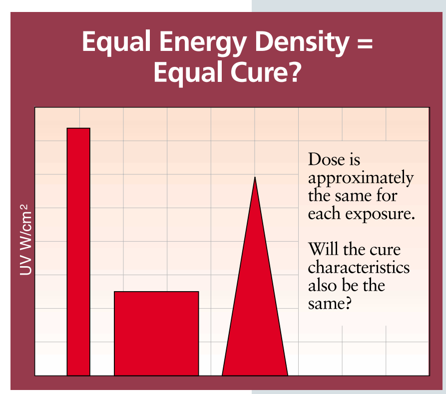


Figure 22: Equal numbers of Joules do not always lead to equal cure characteristics. It is important to establish and maintain irradiance levels for your process.

It is important to determine the minimum irradiance value needed for your process. Staying above the minimum will allow you to get the adhesion and penetration through your coating. Remember that the longer wavelengths (UVV) have better chance at penetration than the shorter wavelengths (UVC). Often times the UV system with the higher irradiance will allow you to run at faster belt speeds. Higher irradiance values may also increase cure rate efficiencies.

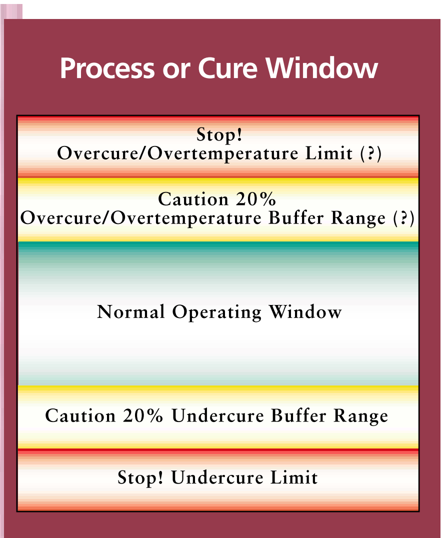


Figure 23: An easy to understand graphic of the Process or Cure Window. Establish the window for your process and stay in the green zone.

A radiometer can report the highest irradiance measured (peak irradiance) and/or a profile of the irradiance over time (irradiance profile).

The radiant energy density is important for total and complete UV cure. Historically, the UV radiant energy density (dose) has been the only UV exposure guide number supplied by formulators. Recently, some formulators have also started supplying the irradiance value required for a particular coating.

Supplying only the radiant energy density is supplying only part of the information needed to establish process control. Dick Stowe of Fusion UV Systems compares this to a recipe that only gives the cooking instructions in degree hours. Imagine getting a cookie recipe that states to bake the cookies for 100° hours. Does that mean 100° for one hour, 200° for 30 minutes or 400° for 15 minutes?

By varying the irradiance and time, three different exposure profiles can be tested that deliver the same radiant energy density to a substrate instead of cookies. Even though each substrate received equal joules, the results will vary based on the irradiance levels (See Figure 21 and 22).

With radiant energy density, take readings at a slow line speed and extrapolate to faster production speeds if needed. The relationship of radiant energy density to line speed is inversely proportional. $Ex = Ey \cdot Vy/Vx$ where E equals energy and V velocity.

If Ey= 400 mJ/cm^2, Vy= 20 fpm, what happens to Ex when Vx moves to 40 fpm?

Process Windows

A process window is the range that will produce the desired results (See Figure 23). One or more of the following can be used to evaluate the results:

Adhesion, hardness, flexibility, gloss, texture, stain or scratch resistance, chemical rub, cross hatch, abrasion rub, color ID, registration

A large process window is easier to maintain than a small process window. With a small process window, one small change may push the process into the no cure zone. Think of having to align several windows with the goal of shooting an arrow through the windows with one try. The bigger the set of windows, the easier it is to line things up and get the arrow through.

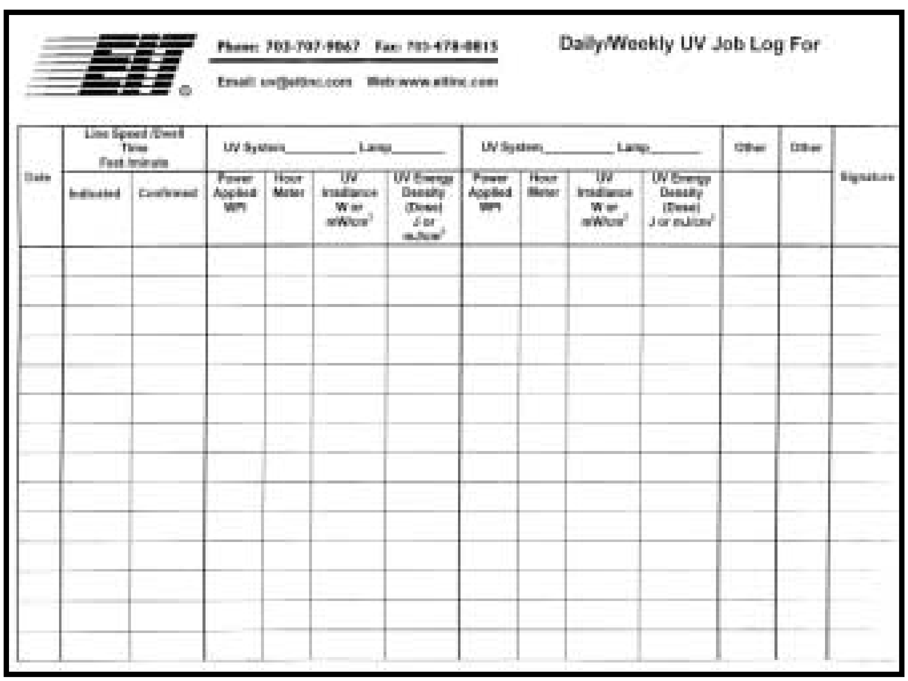
UV Measurement and process control on the production floor consists of measuring, monitoring, verifying and documenting that the equipment and key optical components remain within the specified limits for the process. Hopefully you have been supplied information from your formulator and have a good idea on where to start for your process and application.

Establishing and Maintaining Process Control or Process Window

The best time to establish process control or a process window is when things are working. Trying to establish process control when things are not working (and a big job is due) is frustrating. Calling to purchase a radiometer for overnight delivery when your line is down will only tell you the current irradiance and radiant energy density on your system, not the conditions when things were curing.

Establishing and documenting process control takes work and it takes time. Consider it an investment or the establishment of a solid foundation that will pay you back down the road when the honeymoon is over. It may take 1-12 months, but sooner or later your UV honeymoon will be over. Coordinate operator training and procedure documentation with your work to establish control.

Most applications are concerned with defining the lower limits at which a process will work. At what point do you reach an under cure situation? To find this point, run tests in which you gradually increase the line speed until you produce an under cure situation. Document this failure point by recording the para-


Daily/Weekly UV Job Log For

Date	Line Speed/Dwell Time Feet/minute		UV System_____ Lamp_____				UV System_____ Lamp_____				Other	Other	Signature
	Indicated	Confirmed	Power Applied WPI	Hour Meter	UV Irradiance W or mW/cm²	UV Energy Density (Dose) J or mJ/cm²	Power Applied WPI	Hour Meter	UV Irradiance W or mW/cm²	UV Energy Density (Dose) J or mJ/cm²			

Figure 24: Sample job log that can easily be modified for your particular process.

meters — irradiance, radiant energy density, power applied to the system, line speed. This line is the "red-yellow" line on the diagram. If you like to live on the edge, the point of under cure is the point where you need to stop production and correct the situation. I suggest building a "yellow" cushion or caution zone of approximately 20% on your process window that allows for slight changes during a production run. Above the caution area is the green "go" zone. I always want to start a new job in the green zone and hopefully also wind up the job run in the green zone. Once you know your system, you will be able to anticipate slight changes that may cause you to drift into the yellow caution zone. The job should be able to continue running if you move into the yellow caution zone but I would never start a new job unless I am in the green zone.

Is there such a thing as too much UV? Formulators will argue that from a chemistry standpoint there is no such thing as "over curing" or too much UV. Maybe a better term would be "over temperature" of the substrate. The purpose of mentioning "over cure" is not to open a discussion on UV chemistry mechanics but to point out that some applications may have to monitor the process "over curing, over temperature" situations. If your substrate is heat sensitive, work with your UV equipment suppliers to minimize the amount of infrared reaching the substrate. You may also want to establish an upper process limit for some applications. Instead of increasing the line speed and documenting changes, slow down the line speed until you reach a point that causes you to reject the product. Document this point and build in a caution zone, much as you did for the under cure point.

How often should you monitor and take UV readings? By the job? Hour? Shift? Day? There is no easy answer and you will have to let the information that you collect and your process dictate the frequency of readings. It is easier to collect more readings at first to establish a baseline with the idea that you can always back off later in the frequency of readings after you look for trends in the data.

If you only remember one thing from this article remember that *UV measurement can't help you unless you document and record the readings!*

Job, Performance or Process Control Logs

Your Job Log (Figure 24) is your record documenting the performance of your UV system. It is a place to keep performance information on your system that can be referred to when things are not working. Keeping a Job Log is not rocket science-it requires a dedicated clipboard, log sheet designed for your equipment and the discipline to take and record readings. A Job Log can easily be customized with a word processing or spreadsheet program. Keep the clipboard in the same place and record information only on the log, avoiding the urge to keep information on small scraps of paper. Assign 'ownership' or responsibility of the Job Log to a specific individual in your company.

Suggested Steps If Your Process is Not Working or You Are Outside the Process Window

1. If the process window has been documented and readings have been taken on a regular basis, relax and breathe deep and review your Job Log. Was it a gradual change over time towards the identified caution area or was it a sudden change? Any changes to the process? Equipment? Suppliers?
2. If you have not been keeping track of things or have not yet done your work on establishing your process window:
   - Start asking for help from the UV Cure god(s). The amount of help requests increases as the production throughput decreases.
   - Hope that your boss buys your story that it is a supplier problem (bad batch of ink, substrate problem).
   - Call the supplier back, apologize that you blamed them, beg for their help after you find that it is not a supplier related problem
   - Start polishing your resume.
3. Confirm key equipment settings; measure UV levels to double check or confirm current readings (How did press station #3 on press #1 get switched to 200 WPI instead of 400 WPI?).
4. Perform UV system maintenance: Observe all safety precautions, follow manufacturer's instructions and company procedures to check and clean the reflectors, rotate the bulbs, check cooling and air flow on the housing
5. Measure the UV again, looking for improvement and movement back within the process window
6. Replace UV bulbs or adjust key equipment variables until you are back in your process window
7. Work and communicate with all suppliers in good times and bad times

Conclusion

If you want that honeymoon feeling ("new relationship characterized by an initial period of harmony") to last with your UV system you are going to have to put a little work and effort into the relationship. In order to live with your UV system, get to know, understand and respect it and your UV process. Learn how to maintain your system. Knowing your UV system will save you time, money and maybe even a few customers. Establish and document your process window and work to monitor it on a regular basis. Communicate with your suppliers on a regular basis, not just when you are having problems.

Acknowledgements

The following people have helped with the preparation of this article by providing materials, guidance, graphics, lab tests, constructive criticism or proof reading:

Dick Stowe of Fusion UV Systems, Gaithersburg, MD

Gerald Davis, Greg Ellis, Bill Sparks and Troy Smith of UV Systems, Houston TX

Sue Casacia, Molly Byrne and Dan Thomas of EIT, Sterling, VA

UV Technology, Cincinnati, OH

UV Process Supply, Chicago IL

Bruce Ridge and Russ Petty of Nazdar, Shawnee KS

Charlie Vendeville of Avery Dennison, Painesville, OH ☐