UV MEASUREMENT AND PROCESS CONTROL FOR UV FORMULATORS

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INTRODUCTION

"Anything that you can measure, you have better chance of controlling. Things that you don't measure will eventually become the cause of mysterious problems"

Larry Goldberg-Beta Industries

Communication, both in your UV formulation lab, and between your lab and customers is an important key to your success and prosperity with UV formulations.

The paper reviews the variables that need to be measured, monitored, maintained and communicated both in your formulation lab and during the manufacturing process. Establishing an operating 'window' for your formulation and communicating it to your customers is essential for moving from initial lab trials to production. Maintaining consistent 'curing' during production is essential for long-term success. Consistency and profitability is achieved when both your staff members and customer staff members communicate in the same language and understand the variables involved with the process.

The goal of successful companies is not to make the most of a product but to make the most of a product that is of good quality and can be sold (i.e. not returned) at a profit. To achieve and maintain good quality and profit, production costs, time, throughput and materials all need to be established, measured, monitored and maintained at acceptable levels. Communication and a thorough understanding of your formula, application equipment, curing equipment and customer's process is essential.

Having your customers operate their manufacturing process in a 'zone' or 'window' where it works best will optimize production and reduce waste, saving the company time and money. It will minimize the 'your product is not curing calls' that you receive. The universal reaction when the product does not cure is to call the formulator and blame the problems on a 'bad' batch of product. When things go well, you seldom hear from the customer. How many calls does your company receive complimenting your staff on a 'good' batch of product?

R.W. Stowe of Fusion UV Curing Systems describes a process window as the range of a measurable production variable within which "cure" meets an acceptable requirement.[1] Depending on your application or process, one or more of the following could be used to judge if the product is acceptable: adhesion, hardness, flexibility, gloss, texture, stain or scratch resistance, chemical rub, cross hatch, abrasion rub, color ID, registration.

Often many variables have to line up for the UV process to consistently work at levels that produce quality products and profits.

TARGET NUMBERS-STARTING

Goals are deceptive-the unaimed arrow never misses.

From Kimo's Rules by Charles Knief

Pick one of your UV formulations. What are the requirements and UV conditions needed to cure this product for a given application? Write down the guidelines, if any, that you provide for the customer?

Do you understand the requirements or guidelines? How did you get these numbers? How do you communicate these UV conditions and requirements needed for this product to your customers? Do your customers understand your requirements? Do the requirements have measurable goals or targets to aim for? If there are no UV or process targets or goals, the arrow above will always be on track.

Note: Many formulators are reluctant to publish or share 'cure' targets or guidelines. Formulators are afraid of claims if the customer follows the published guidelines and proper 'cure' does not take place. The formulator needs to emphasize that the guidelines are suggested for a certain set of conditions and that their technical reps will work with the customer to 'tweak' the guidelines for their equipment and process.

If the starting guidelines from a formulator are not present or not clear, the customer will have to do extensive testing on their own before starting production to find the range of conditions that work best for their process.

If your product cures initially, the customer may elect to skip the testing or qualification process to establish needed cure conditions. Often this happens with new UV equipment that is operating at peak efficiency. The first time your formulation does not cure, the customer will assume that you have produced a 'bad' batch of inks or coatings-remember the universal reaction. Almost all times it is not a 'bad' batch of inks or coatings but a change in the customer's UV system and/or a lack of a preventative maintenance program.

Lack of guidelines, goals and targets can be expensive for both the customer and the formulator.

COMMUNICATION

Success with UV comes from understanding the process and the UV equipment. The customer should involve all suppliers (formulator, substrate, equipment) in testing to establish that the process works. As a formulator, you should be able to supply the customer with some general 'starting' targets. (What did you write down above?) These numbers are starting points that may have to be adjusted for the customer's equipment and process.

In an ideal world, your UV system would be matched to the formulation. 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. Can the UV system the customer wants to use deliver the UV needed for the process? Or will so many changes be needed to your formulation, the process and/or the equipment that the UV system is not well suited for the particular process?

To maintain process control once you have your targets, there are several variables that you need to monitor, maintain and document in addition to talking 'watts' and 'joules'. Joules and watts are an important part of the overall picture but not the only part.

TERMINOLOGY

RadTech International North America has produced a Glossary of Terms for UV Curing Process Design and Measurement. The glossary is posted on the RadTech website (www.radtech.org) and it can help all 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 more correctly describes the concept of UV arriving at a two-dimensional substrate than the word intensity.

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, an instrument called a 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.

PROCESS VARIABLES

The actual variables from the list below that you and your customer should consider documenting, measuring, monitoring and maintaining will depend on the process and equipment.

Line Speed/Dwell Time: The line speed/dwell time is important because it controls the amount of time that the 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/cm^2) reaching the substrate is inversely proportional. Doubling the line speed will cut in half the radiant energy density (dose). Check and confirm the line speed independently of displays or indicators on the system. Variations of 20-25% when comparing the indicated speed to the actual speed are not uncommon. Based on the UV equipment in your formulation lab, it may or may not be possible to formulate at the same line speed as the customer. Joules and watts should be compared, not feet or meters per minute.

Hour Meter: Imagine receiving two tickets to an important football (soccer) match-say Brasil in the next World Cup final. Would you go to be a part of the excitement and crowd even if it meant sitting in seats very high in the stadium? Probably, yes. Hour meters on UV systems can also get you into the stadium-but there is no guarantee of your view or whether you will be able to see what is going on inside the UV system.

Many UV systems have an hour meter that allows the user 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 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 to identify trends in performance of the current bulb(s) and system.

- How many hours can be expected from a bulb?
- Is the performance of the bulb stable? Over how many hours?
- Can adjustments be made to compensate for changes in the bulb over time?
- Are these bulbs the best value? Does a bulb that costs more initially give better, more stable and longer lasting useful performance in the UV system?

Amp Meter: Many UV systems have an amp meter that allows the user to track incoming electrical power. Under 'normal' conditions, the incoming electrical power may vary by as much as twenty percent. During times of heavy demand (hot summer or cold winter days) or reduced/limited supply, this variation could be even greater. Will a drop in incoming power reduce the amount of UV reaching the substrate to a point where the product is no longer curing? Keep an eye on the amp meter-especially if there are power fluctuations in your area or if the process is running close to the minimum amount of UV needed to cure the 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 200-600 WPI or 80-240 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 reaching the cure surface. The irradiance value is much less than the applied power number.

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. It is also a big mistake to assume that UV systems with the same rated lamp power deliver equal amounts of UV to the substrate. 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. 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 over 50%. Most UV systems use an elliptical or modified elliptical design. 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. It is important to maintain the systems as designed for the process. On wide (90 cm/36"+) arc systems, watch for sagging or bowing of a bulb. This slight sag can alter the design and reflective geometries in the system. The potential for wide arc bulbs to sag is a reason to rotate the UV bulb when cleaning the reflector. Profiling radiometers that plot the irradiance as a function of time are available. They can help determine reflector conditions and changes over time.

Spectral Output: 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. The UV portion of the electromagnetic spectrum includes wavelengths from approximately 100 to 400-450 nanometers. Four to five general wavelength ranges are commonly designated in the UV area of the electromagnetic spectrum.

VUV: 100-200 nm While this area is important in some electronics manufacturing and to scientists looking at UV radiation in space, Vacuum UV is not normally measured in coatings 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.

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 a coating. UVC (254 nm) is also used for germicidal treatment of air and water.

UVB: 280-315 nm The UVB bandwidth can assist with the curing of inks and coatings if a UVB responsive photoinitiator is present in the formulation. UVB is probably best known for the effects it can have on human skin.

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 coatings are formulated to respond to UVA.

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 "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.

System manufacturers can tell you what types 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 on value (stability, consistency, effective useful UV output over time) instead of the lowest dollar cost per unit.

Unique variables: Evaluate if the process has any unique variables which need additional monitoring. Examples could include inert curing with nitrogen or external process variations where the substrate, formulation or facility experiences wide swings in temperature, humidity, static, handling or storage conditions

For each variable above, decide how it is going to be monitored or checked, the frequency, and who will be responsible. After tracking the information, decide if you can measure some of the variables less frequently.

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: Instruments that are 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). Instruments known as spectral radiometers may also report the irradiance in W/cm^2/nm, which is the irradiance for a very narrow spectral bandwidth-often 5 nanometers or less. 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. Caution needs to be exercised when making comparisons between different brands of absolute instruments. Different manufacturers look at different portions and bandwidths in the UV portion of the spectrum.

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. Unless the readings are coordinated with an absolute reading radiometer, it is harder to make direct comparisons between different systems and communicate with suppliers because '100%' on one system may not equate to '100%' on a second system. Relative instruments or instruments inserted in the process are also dependent on the location of the sensor.

FORMULATION EXPECTATIONS AND STRATEGIES

Some formulators are reluctant to supply clearly defined cure guidelines because they fear they would be forced to take a product back if it did not cure under the condition(s) specified. If guidelines are supplied, they are often vague (product cures with a medium power lamp) or interpreted as being fixed and written in stone instead of being starting guidelines, which need to be adjusted for a particular process and UV system.

Often times, the ‘same’ formulation is expected to work on different substrates and with a variety of application methods. The thickness of the ink or coating will vary with the different application methods. The formulation is expected to ‘cure’ on a wide variety of UV sources. Even within a single company, the output and effective UV delivered to the cure surface from the UV equipment will vary greatly. Factor in different brands of equipment, different types (arc, microwave, pulsed, spot, flood), different power classes, single lamps, multiple lamps and varying states of maintenance on each system and you have the potential for wide variations in the amount of UV available to cure your products.

Your customers may have limited knowledge of UV and rely entirely on you for knowledge and support. Preventative maintenance to keep the equipment in peak operating condition is often absent. Watch out for the universal customer reaction when things to not cure.

The only guideline number provided with some products is a joule ‘dose’. The instrument, spectral bandwidth and collection techniques used to get this ‘dose’ (energy density) value are usually not given. From a formulation standpoint, it is not enough just to specify the number of joules required to cure your products. Equal numbers of joules can be obtained from vastly different exposure profiles. A long exposure (slow process speed) on a system with low irradiance can give the same number of joules as a very brief exposure on a system with high irradiance. Even though the number of joules may be equal, the cure characteristics in the final product can be vastly different. Still not a believer? Leave your product out in the sunshine for a few hours and see how this cure (sunshine) compares to the cure from a brief exposure with an intense UV system.

Establishing the UV cure guidelines or zone where the process best works requires the formulator to specify:

- UV irradiance (W/cm^2)
- UV energy density (J/cm^2)
- Type or spectral signature of the UV required to match the package of photoinitiators in the formulation. This is often expressed by the bulb type-mercury or mercury along with an additive.
- Impact of infrared energy. Is IR needed to assist with the cure process or could too much IR impact a temperature sensitive substrate?

When you communicate measurement values, include the bandwidths or instruments used to take the measurements.

The desired cure characteristics (depth of cure, surface properties such as texture, scratch, stain or chemical resistance) in the end product will help determine the needed exposure profile. Some formulations respond better to joules and some better to watts. Establishing the window or zone for each process requires testing and experimenting with the process and formulation. Tweaks, balances and trade-offs are often needed to achieve the desired results.

The formulator needs to work with the customer to:

- Determine the desired end properties (adhesion, hardness, flexibility, gloss, texture, stain or scratch resistance) in the product.
- Determine the production parameters-application and manufacturing methods, manufacturing environment, production speed required to make the process profitable. Are there additional operations that need to be performed on the substrate before or after the UV operation?

In an earlier section, the ‘ideal’ scenario was described in which the UV system would be purchased last and would match or exceed the requirements needed for the process. In the real world, a formulator often needs to work with a customer’s existing UV system. Your customers will have a variety of UV equipment. How flexible is the equipment in your formulation lab in duplicating the UV conditions that will be encountered during production?

Problems can arise between the formulation lab and production under the following circumstances:

- The production and formulation lab UV systems are operating on different irradiance scales. Formulations may cure easier and have better adhesion in the lab with high power arc or microwave sources producing UVA irradiance values of 1000-4000 mW/cm^2 than in a production environment using arc lamps with UVA irradiance values of 150-400 mW/cm^2. If the opposite is true and the UV source in the lab has a relatively low irradiance value compared to the production environment, you may be adding unnecessary expensive 'extras' like photoinitiators to the formulation to get it to cure

- The UV system in the lab is older and it is not well maintained. How many hours are on the current bulb in your UV lab system? When was the last time preventative maintenance was done on the system? Have technicians rotated through the lab and the one in charge of preventative maintenance been away from his position longer than you think?

- The UV system and power supply in the formulation lab do not support different types of UV bulbs? Can your system support mercury as well as mercury additive bulbs? What bulb is in your system now? Is this clearly identified to the technicians working on the system?

- Is the height and focus of your UV system adjustable to support both focused and non-focused trials? What about different types of reflectors-both shapes and materials.

- If you are running two lamps in your lab, have you measured each lamp individually or do you just assume that they are equal?

- How do you control and confirm that process variables such as line speed and applied input power are set and maintained where they need to be?

Develop a master file for each customer with the performance characteristics of each of their UV systems. When a customer tells you that they want to run the process on a certain line, you should know if the line outputs 150 or 3000 mW/cm^2 of UV irradiance. If one type of UV system (arc for example) is common to all of your customers, you might be able to get by with a single UV system in the lab. If your customers use a variety of different types of UV systems, consider more than one system to match what your customers are using. Consider investing in UV systems for your lab with variable power supplies instead of power supplies with fixed choices-often two or three. Make sure that you system supports different types of bulbs.

When formulating in the real world (customer already has UV equipment) and trying to duplicate the UV conditions on a customer's system:

1. Use a radiometer to assist with your measurements. Use it as it was designed.
2. Adjust your system to match the bulb type and approximate focus of the system that the customer is using. A profiling radiometer that plots the irradiance as a function of time can assist you with documenting and adjusting the focus on UV systems.
3. Adjust the applied power settings on your UV system to get your readings in the same irradiance range as that which your customers are using. The readings do not have to be exact but should be close. A variable power supply is helpful for this. Refer to the owner's manual for proper use of the variable power supply-generally there are minimum input power levels to maintain different types of bulbs.
4. Adjust the line speed to approximate the energy density values, once you have adjusted the irradiance values. In systems with multiple lamps, it may be necessary to run the radiometer or test sample though several times.

Many times you will want to give your customers minimum values for irradiance and energy density. Finding the minimum values often means running tests in which you gradually increase the line speed or decrease the applied power until you produce unacceptable results. Document the failure point(s) by recording the parameters - irradiance, radiant energy density, power applied to the system, line speed.

It is best to give these starting numbers to your customers during pre-production tests instead of trying to do this while production is ramping up or running.

Once you have established the failure point, build 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. Always start and hopefully wind up job in the green zone. Anticipate slight changes that may cause you to drift into the yellow caution zone. If you move into the yellow caution zone, finish the current job but do not start a new job.

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. Remember that:

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

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.

JOB, PERFORMANCE OR PROCESS CONTROL LOGS

Your customers should use a log 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 the process.

What kinds of things can you include on the process control log?

- Indicated vs. actual process speed
- Hour meter
- Applied power settings (WPI/WPCM, Amps)
- Irradiance (W/cm^2)
- Radiant energy density (J/cm^2)
- Lamp matched to chemistry
- Focus/reflector condition
- Date/job number
- Operator signature
- Mesh count
- Formulation type
- Pass/fail on specific QC tests-cross hatch, rub, registration
- Maintenance log of system
- Maintenance due date
- Radiometer type/bandwidths

<u>When things stop working:</u>

1. Examine the 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. Confirm key equipment settings and measure the UV.
3. Perform UV system maintenance and clean the reflectors, rotate the bulbs, check cooling and air flow on the housing.
4. Measure the UV again, looking for improvement and movement back within the process window.

5. Replace UV bulbs or adjust key equipment variables until back in the process window.
6. Work and communicate with all suppliers in good times and bad times.

UNDERSTANDING MEASUREMENT INSTRUMENTS

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 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 reporting 900 mJ/cm^2, report 900 mJ/cm$^2_{\text{(EIT UVA)}}$ or 900 mJ/cm$^2_{\text{(320-390 nm)}}$ to avoid misunderstandings.

Filter and Detector Specifications: Even within a single manufacturer's line of products it is normal to expect small variations in the optical performance of any of the optical components.

Data Collection Speeds: For repeatable, reliable results, a UV instrument needs to collect an adequate number of samples. Some production speeds have moved to the point where the instrument collects samples under the most intense peak one run but just misses the most intense point on the next run. This can lead to wide variations in the reported irradiance values.

Out of band rejection rates: The way that your instrument deals with energy outside the UV band you are measuring can influence the readings.

Temperature: Wide swings in the temperature of the photo detector(s) used in instruments can lead to differences between readings. Try to be consistent.

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: Make sure the dynamic range of the instrument matches the irradiance levels of your system.

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.

CONCLUSIONS

1. Communicate clearly to your customers.

2. Educate your customers and establish a good working relationship-especially when things are curing well. This will help them to avoid the universal reaction where they automatically assume that you have produced a ‘bad’ batch of inks or coatings.

3. Provide your customers with starting guidelines on what it takes to cure your products. When you communicate measurement values, include the bandwidths or instruments used to take the measurements. At a minimum supply them with:
   - UV irradiance (W/cm^2)
   - UV energy density (J/cm^2)
   - Type of UV required-often expressed by the bulb type-mercury or mercury additive
   - Impact of infrared energy. Is IR needed to assist with the cure process or could too much IR impact a temperature sensitive substrate?

4. Set your formulation lab up with flexibility in mind. Use numbers to communicate within your facility and with customers.

5. Have your customers operate their UV process in a ‘zone’ or ‘window’ where it works best to optimize production, reduce waste and save their company time and money.

6. Identify the target numbers and variables in your process. Help your customers to set up a program to track and monitor the variables. Use a log to predict maintenance and minimize downtime.

7. UV measurement is an important part of the maintaining the process in the ‘zone’ or ‘window’. Use your UV measurement equipment properly and in the manner in which it was designed.

8. Encourage your customers to communicate with their suppliers on a regular basis, not just when there are problems.

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REFERENCES

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