Conclusion

In addition to providing superior performance properties, UV processing harvests the best of both worlds: the ease of applying liquids and the environmental benefits of powder coatings. The economic benefits of UV processing coupled with the performance properties of UV coatings makes obvious the superiority of UV processing over other competitive technologies. Where other coating technologies rely on the same raw material 'building blocks' that have been available for decades, UV formulators enjoy an fast growing arsenal of newly developed, high performance raw materials. This makes UV technology the most dynamic, fastest evolving and economically attractive coating technology available today.

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ABOUT THE AUTHOR

Andrew A. Sokol has been involved in the UV/EB industry for over 12 years. His experience in both UV chemistry and equipment includes the R&D and industrial applications in both government and public arenas. Mr. Sokol has been awarded two US letters patent in the area of UV technology with additional patents pending domestically and internationally.

An active author and speaker, Mr. Sokol is the founder, partner and Director of R&D for UV Coatings, Ltd., Cleveland, Ohio.

<u>Monomers</u> – Low molecular weight acrylates. This component contributes physical characteristics such as hardness, softness, elasticity, etc. Monomer resins are not to be mistaken for raw material monomer which are used to make the acrylate resins i.e. acrylic acid.

<u>Oligomers</u> – High molecular weight acrylates, which incorporate physical properties from materials such as urethanes, polyesters, silicones, etc.

3. Pigments, Fillers and Additives – Control and impart color, adhesion, surface properties such as gloss, slip, marring, filling properties of porous substrates and so on.

UV coatings require a minimal dwell time (time between application and cure) on parts. Minimal dwell time minimizes the potential for incompatibilities to manifest between the coating and substrate. Truly zero V.O.C., UV curable coatings require no flash-off, and UV processing can immediately follow application of the coating. Once cured, the coating is extremely durable and stable - immediately making parts ready for packing, shipping and invoicing. UV cured coatings tend to be chemically stable and resistant to chemical attack, but even strippable coatings can be produced through formula design.

Formulators enjoy a growing arsenal of raw materials from which to design coatings. The formulation latitude for coating properties is impressively broad allowing for 'lock-and-key fit' of the coating to its application. Where circumstances dictate the need to custom engineer a coating product, it is critical to establish a firm and *unchanging* checklist of desired coating properties and test methods by which both parties may verify such properties.

Though formulators are capable of engineering coatings to meet the customer's needs, purchasing off-the-shelf coatings avoids the additional expenses of custom formulation/development. Communication between the coating end user and coating supplier is critical during the development of a new coating. Once a satisfactory coating product is tested, it should be implemented with any additional enhancements carried out as product development. The coating supplier should be able to provide information from their experience with their product that will enable reputable UV equipment vendors to recommend and quote suitable UV equipment or systems:

Recommended Lamp Type and Configuration

UV coating formulators know exactly what wavelengths UV their formulations react to. These frequencies may, however, be considered proprietary resulting not in a frequency recommendation, but the recommendation of a lamp *type* i.e. mercury bulb, gallium bulb, "H" bulb or other.

The availability of UV equipment to a formulator is vital to successfully developing and testing a viable coating product. The availability of UV equipment is the only way a coating supplier can recommend, with any confidence, what lamp type, dosage and lamp configuration are required to properly cure the coating.

Do not hesitate to request from you coating supplier a diagram showing:

A. Recommended lamp positioning and distances relative to the part (angled, cantered, etc.);
B. Recommended lamp types i.e. Mercury, 'D' Bulb, Iron Lamp, Gallium Lamp, etc. If there are multiple lamp types recommended is there a recommended lamp sequence? Lamp sequencing serves to differentially effect surface cure versus through cure or sequence what part of the coating is cured in what order;
C. Recommended lamp operating power setting(s) (200 Watts/Inch, 300 W/In, 400 W/In., etc.).

Recommended UV Dosage

Recommended UV dosage should be expressed as J/cm^2 (Joules/ cm^2), mJ/cm^2 (milliJoules/cm^2). Be aware that UV radiometers need to be recalibrated at least once a year. Do not accept from your supplier a recommended UV dosage value of simply 300 Watts/Inch. This is a lamp power setting on the UV equipment and provides no information on the UV dosage required for curing the coating.

The integration of UV equipment systems must be performed by reputable vendors experienced in designing and installing UV curing systems as well as supporting the customer after installation.

It is a good idea to visit your potential coating supplier to meet with your potential support team. Support teams are comprised of a sales/field representative, in-house sales contact, and a technical support contact who may be the product manager/chemist or a technical support representative.

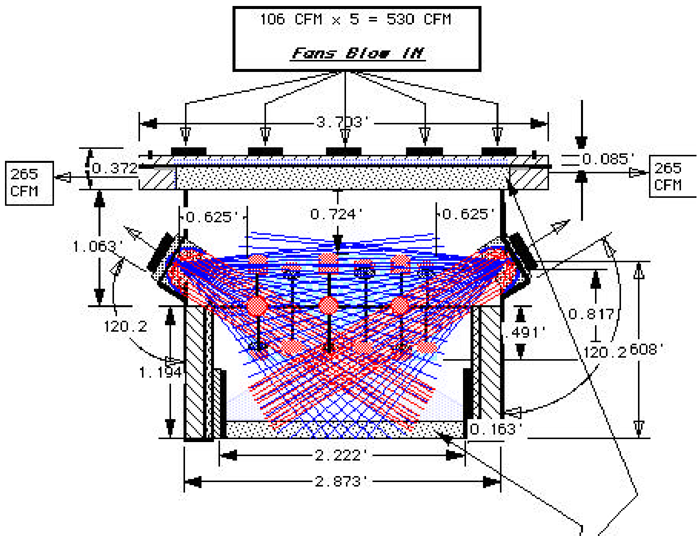
During your visit review your project goals tour lab and production facilities and ask questions. The presence of various types of UV equipment, analytical and physical testing equipment should be evident – ask questions about the systems. Unless you are a competitor, your coatings supplier should not refuse a tour request unreasonably.

__2. REACTION PROPAGATION__

Free radicals initiate a chain reaction where reactive sites on the acrylate molecule (functional sites) bond together or cross link to start forming a polymer.

Free radicals are extremely energetic molecules capable of producing an extremely fast chemical chain reaction. The reaction may be as slow as a several minutes (sun cure) to as fast as 0.00000000001 ($1.0X10^{-11}$) second (beer can printing lines)! [2] UV curable materials are inhibited from premature hardening by the addition of stabilizers, which work with ambient oxygen to scavenge and neutralize any free radicals that may form during the handling or storage of UV curable products.

In the absence of oxygen, such as under nitrogen blanketing, photopolymerization has been observed to be 17.5 times faster than in the presence of oxygen. [8] Initially, photoinitiators (UV 'sensitizers') were not as efficient as those available today. Early UV curable coatings required the use of nitrogen blanketing to achieve adequate cure speeds. Current photoinitiator chemistry has rendered nitrogen blanketing obsolete, save for special applications. Advances in curing efficiency coupled with highly UV reflective materials in curing chamber construction have effectively eliminated a primitive UV curing issue: "line-of-sight" cure.



A vector ray trace drawing depicting UV distribution within a curing chamber.

Of special note, UV curing is defeated by the addition of solvents to the coating by production line operators. This practice, stemming from historical use of solvents and 'retarders' with solvent borne coatings, is the cause of such additions being made to UV curable products. Attempts to extend coverage by adding solvents only causes problems on UV processing lines. It must be kept in mind that ONE, 1.0 mil coat of solvent free, 100% solids coating is the same as TWO, 1.0 mil coats of 50% solids or FOUR, 1.0 mil coats of 25% solids.

In UV curable coatings, solvents such as mineral spirits, alcohol, glycol ("butyl"), and the like confound the advantages of near instantaneous UV curing by imposing a flash-off (drying) time. Any such solvent addition which does not flash-off and remains in the coating during the actual cure will cause at least one or a combination of the following to happen:

A. Retard/inhibit the UV reaction
   May cause problems that can masquerade as light source/equipment issues
B. Manifest finish flaws such as orange-peel, bubbles and so on.
   May be mistaken for equipment issues or
C. Autoignition of solvent fumes
   UV lamps operate above 1500^{o}C well above the ignition temperature of most solvents

Rather than using solvents to control coating viscosity, UV curable coatings should be formulated to be used within an optimal viscosity and temperature range without the need to use solvents as a viscosity control. Properly formulated UV curable coatings should never need to be diluted with solvents.[9]

__3. REACTION TERMINATION.__

As the number of available reactive acrylic sights are consumed during polymerization, the chain reaction shuts-down.

Once the reactive sites are polymerized, the photoinitiator fragments neutralize by recombining. The photoinitiator is either trapped within the or becomes part of the polymer if it is a functionalized (polymerizable) photoinitiator.

COMPONENTS OF UV CURABLE COATINGS

UV curable coatings are comprised of the following basic components:

1. *Photoinitiators* – Absorb UV light and start the polymerizing free radical reaction;
2. *Acrylic Resins* – Primary resin family of UV curable materials

corrosion inhibitors, which displace water and passivate metal with the inhibitors. E-coat forms an effective barrier by being deposited as a near perfect barrier film.

The ability to engineer coatings with specific lock-and-key physical properties creates a extraordinary coating system for a wide range of metal coating and finishing applications.

UV technology is such a competitive advantage that its utilization is a closely guarded secret by manufacturers using it in their production. As such, case studies or photographs of operational UV production lines are rarely if ever released by manufacturers. In addition to remarkable processing advantages and physical properties, UV processing offers the following competitive advantages to manufacturing operations:

- UV Eliminates the need for third party coating due to Title V EPA emission limitations;
- In-house coating operations eliminate costs of third party processing.
- In-house coating eliminates freight costs on parts to/from third party coating service
- In-house coating Eliminates third party mark-up
- Low Implementation Cost - Low Initial Capital Investment with ROI of 1-5 years
- UV eliminates need for large ovens freeing-up plant floor space
- UV processing decreases energy usage from conventional ovens
- UV's Speed of processing facilitates quality assurance - parts can be inspected immediately. Risk of coating defects minimized with minimal drying time. Parts can be stacked or palletized immediately with no post cure.
- Environmental savings are realized - hazardous waste disposal and shipping minimal
- 100% solids, UV curable coatings are non-flammable; potentially decreasing insurance costs
- Dunnage remains cleaner as no uncured coating comes off on dunnage.
- 100% solids, UV curable coatings are recoverable and reusable without effecting performance or composition
- 100% solids, UV curable coatings cover more square footage efficiently and effectively.

THE MECHANISM OF THE UV REACTION:

On exposed to UV light a UV curable composition undergoes the following:

1. Reaction Initiation
2. Reaction Propagation
3. Reaction Termination

1. REACTION INITIATION

The Photoinitiator component of a UV curable formulation absorbs UV light energy and generates highly reactive "free radicals".

Each UV curable formulation requires a certain threshold amount of UV energy to initiate the polymerization reaction. To illustrate the importance of achieving this threshold energy level, imagine the opening break of a billiard game: first, the game initiating ball requires enough energy to get to the target ; secondly, depending upon how much energy the ball carries, the break may be 'fast', 'slow' or embarrassingly ineffective. In this scenario the billiard balls are not defective, they simply did not receive enough energy to cause the desired reaction. This is applicable to UV processing.

In practice, it has been observed that UV cure can be initiated with as little as 0.005 J/cm^2 of UVB (320-390nm). This is the approximate average natural UV level for Miami, Florida at noon (Table 1). Though adequate for tanning, this UV level is far too low to allow UV processing lines to operate at commercially feasible speeds.[5]

In practice, UV levels range from 1.0 to 3.0 J/cm^2 in Flat-line (two-dimensional) systems and as high as 7.4 J/cm^2 and greater in three-dimensional systems. It must be noted that UV energy varies directly with type, number and configuration of UV lamps in operation, while line speed dictates total UV exposure or 'dosage'. Thus, UV levels in industrial UV curing lines can range from approximately 400 to 1,500 or more times the intensity of UV found in natural sunlight.[6]

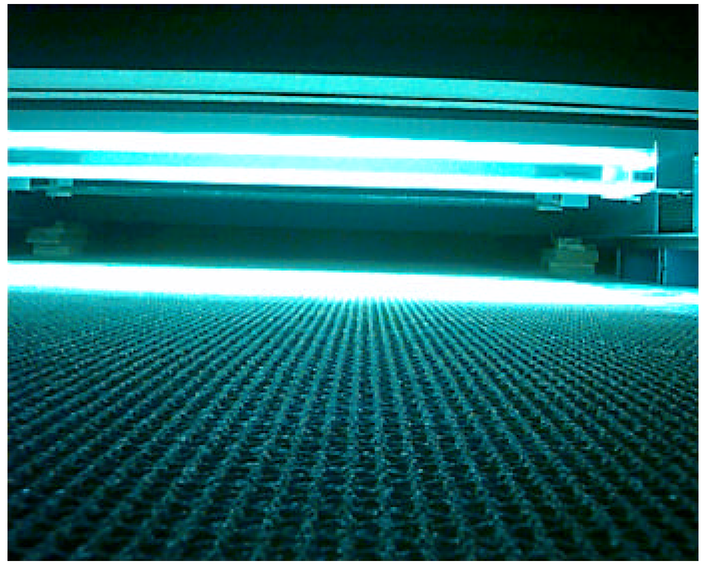
UV SOURCE	MEASURED UV (J/cm^2)	NATURAL UV (J/cm^2) (MIAMI, FLORIDA[5])
Miami, Florida	0.005	1
Typical Flat Line	2.025	405
3-Dimentional	7.4	1,480

Table 1. Perspective: Typical industrial UV processing levels and natural sunlight. With over 400 times the UV normally found in sunlight, these systems are NOT to be used as tanning booths.[7]

THE PROCESS OF UV PROCESSING

UV light energy triggers or 'powers' a desired chemical reaction that converts a 100% solids (liquid), UV curable, coating into a solid. The industrial convention of designating a liquid coating as 100% solids indicates the near total absence of volatile solvents in the coating formulation. The near total absence of volatile solvents eliminates the traditional reliance on evaporation to form a dry film. Eliminate 'drying time' and conversion of a wet coating in to a dry finish occurs in a matter of seconds. NO flash-off or drying time immediately translates into dramatically increased production speeds for the user along with attendant and significant secondary and tertiary economic and logistical benefits.[3]

Green plants and flowers naturally use UV light to power their internal chemical reaction known as photosynthesis, which is the atmospheric source of life sustaining oxygen. Plants derive their energy directly from UV light – the same type of UV light used in industrial UV processing.



A typical 2-D or flat-line curing system. This view, taken from conveyor belt level, shows the actual cure area illuminated by the UV source.

UV light is just beyond the blue end of the visible spectrum for humans. The UV band (400-190nm) is divided into three primary bands designated:

UVA which lies between 440 and 320nm (also known as "black-light");

UVB which lies between 320 and 280nm (also known as erythemal UV), and;

UVC which lies between 280 and 180nm (also known as actinic UV or germicidal UV).

UVC is generally used to sterilize operating rooms and food handling facilities. The odd, pale blue lights seen in restaurant kitchen areas and hospitals are germicidal UV lights. UVC causes 'sunburns' to human eyes and skin. Over exposure of eyes to UV light causes very uncomfortable irritation, identical to that associated with arc welding. This condition is completely reversible, leaving the victim with a greater appreciation for using protective eyewear.

UVB lamps are used for tanning beds and booths as well as for the treatment of dermatitis. UVB can irritate eyes, but to a lesser degree than UVC.

The UV component of natural sunlight spans the entire UVA band, and encroaches into the UVB range.

Generally, UVA and B are used for UV processing of UV curable coatings.

It is important to note that *most materials absorb* UV light, *rather than reflect* UV light. AS UV light is invisible to the naked human eye, transparent materials may appear to be transparent but in fact may be only allowing visible light to pass through and no UV light. The only way to determine how UV opaque a material is to use a UV radiometer to measure how much UV the material allows through. It should never be presumed that a material would block or pass UV light simply from observing the amount of visible light that passes though material. Where special UV transparent quartz passes most UV light, common glass is almost opaque to natural UV. For this reason, tanning through common glass is not possible. This is also the reason why UV light hazards are trivial to manage. Generally, the same safety precautions used for arc welding light are applicable to managing UV processing equipment.[4]

UV equipment vendors provide ample literature and guidance regarding UV light safety. Properly designed, installed and used UV equipment should not pose a serious UV light hazard in the workplace.

UV Curable Coatings: "Liquid Powder"

UV curable coatings are polymeric coatings that are:

A. Applied as a liquid at room temperature;
B. Solidified nearly instantaneously on exposed to UV light into a protective coating, and;
C. Capable of "lock-and-Key" engineering of their physical properties.

Having the benefits of both liquid and powder coating systems, UV curable coatings also have the ability to be engineered to a 'lock-and-key' fit to specific applications.

Multi functional systems such as oil laden phosphate coatings and e-coat systems have an advantage over single coat, single function protective films. The advantage is their ability to effectively protect the metal surface by acting as a barrier to oxygen and water. In the case of phosphate coatings, deposited phosphate crystals act as a reservoir of oil borne

ULTRAVIOLET (UV) CURED COATINGS:

A Technological Overview

By Andrew A. Sokol

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INTRODUCTION

The sheer number of available alloys makes metal coating a complicated feat. Selecting and implementing an appropriate coating that will provide performance while minimizing cost and production problems is more art than science. Accomplished properly the coating of metal components should seem simple and effortless providing years of trouble-free service. Simplicity is the product of a practiced professional whose job is just that: to produce a trouble free product. Professionalism means continuous awareness of new processes and finishing methods with which comes continuous improvement in production and product quality.

An exciting development in metal finishing is the use of UV curable coatings for metal substrates. Recent developments in UV curable coatings for metal resulted in a 'lock-and-key fit' of protective and aesthetic properties for metal finishing. This combinatorial coating system combines the simplicity of applying a liquid coating, and the best protective properties of powder and liquid coatings, hence the designation: "Liquid-Powder". [1]

This article shall provide an overview of UV technology, history, chemistry and it's safety record. A description of UV processing and it's underpinnings will lead into a discussion of the chemistry of coating formulations and how they can be engineered to achieve a 'lock-and-key fit' of coating properties.

HISTORICAL OVERVIEW OF UV TECHNOLOGY

Perceived to be a *radical* new technology, ultraviolet (UV) or more accurately, photopolymer chemistry was born of wartime efforts (WW II & I) to find a synthetic alternative to natural rubber. Those efforts laid the foundation for the commercial implementation of UV processing in the late 50's and early 60's. Early-on experiences with UV resins caused UV processing to be carefully scrutinized, which has resulted in a remarkably detailed, understood and favorable track record in terms of long term health and safety issues. Today's UV technology makes UV processing, if not *the* safest, one of the safest, and most efficient and profitable industrial process technologies available today. [2]

UV processing first found commercial viability in printing applications such as screen-printing. 'First generation' UV curable inks were very viscous, paste-like materials that could only be applied by means of physically transferring it onto a substrate. These primitive, so called 'first generation' UV materials had associated with them severe skin, eye and respiratory.

These UV inks were observed to undergo a viscosity change with increasing temperature. It was a easy leap to guess that simply by heating the paste, it may be possible to lower its viscosity enough to allow spraying it. Attempts to spray first generation UV formulations resulted in widespread health problems – anyone exposed to the spray cloud would never want to spray the material again! The health issues associated with 'first generation' UV materials were so widespread that even as late as the early 90's, the market held it as unthinkable to spray UV curable products. Because of this deep-set negative market experience, coupled with the potential litigation exposure, coating manufacturers halted or never implemented programs to investigate or develop sprayable UV products.

By the late 80's the UV market matured sufficiently to justify the development costs of safer UV raw materials.

Only as recently as the early 90's were research efforts undertaken to investigate the underpinning principles and complications of spray applying solventless, 100% solids, liquid, and UV curable coatings.

In the technology's infancy, UV processing was referred to as 'radiation' or 'rad-cure' technology. This came back to haunt the budding UV industry because the layman factory worker interpreted 'radiation' to mean the type of radiation associated with nuclear radiation. *UV radiation is simply light radiation and is by no means the type of radiation associated with nuclear (radioactive) materials.*

UV processing received heightened scrutiny over the last 30 years, which has resulted in remarkably good record in terms of health, safety and economic benefits. The health and safety record has been so favorable that in September of 1996 UV curable resins (acrylates) were removed as a group from the U.S. EPA's list of suspected carcinogens. This had the effect of spurring on research efforts to design, develop, and market new UV curable raw materials. Correspondingly, the formulator's arsenal of raw materials have grown dramatically which has in turn increased the latitude to design products with specific properties.

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