UV Curing of Ink Jet Printing

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Abstract

The physical properties of UV-cured materials are substantially affected by the lamp systems used to cure them. The development of the intended physical properties, whether an ink-jet printed process colors or solid colors can depend on how well these lamp systems are designed and managed.

Four key variables of a UV curing exposure system, which can be designed or selected to produce the most efficient result, are discussed. Variables include UV irradiance (or intensity), spectral distribution (wavelengths) of UV, total UV energy, and infra-red radiation. The interaction with the optical and physical characteristics of materials such as spectral absorptivity, optical thickness, and diffusivity, result in limitations of the cure "window" Typically, this cure "window" is limited by loss of key physical properties, including adhesion, solvent resistance and scratch resistance. The ability to match all of these lamp characteristics to the optical and physical properties of a UV curable material yields more efficient and stable UV curing processes in production.

Introduction

UV inks have been developed for ink jet printing and for use in the variety of ink jet configurations and applications. The industrial applications of UV ink jet range from large-format multi-color graphics to small, single-color marking and identification. These applications can be divided into two general categories – distinguished by the configuration of UV lamps required to cure the inks.

• **Moving head, wide graphics** systems are characterized by print heads that move across the print area. The printing may be unidirectional or bi-directional. Because the UV cure follows the print head, unidirectional travel requires one UV lamp, while bi-directional travel typically requires two. The substrate sheet or roll advances, usually intermittently, to provide the travel in the perpendicular direction. Two-axis motion, similar to an X-Y plotter, may also carry one or two UV lamps. Because the lamps move with the print heads in moving-head systems, it is desirable that the UV lamps be small and lightweight.

• **Fixed head, high speed** systems are characterized by head arrays that span the print width. They are referred to as "one-pass" systems. The UV lamps are situated downstream, before sheet or roll stacking or rewind, and also span the print width.

Fixed-head systems are typically found where higher throughput and speed are required, and some of the applications include:

- Product Labels (short run), tags and tickets
- Addressing (variable information)/ mailing
- Web Printing (variable data stations)
- Marking (barcodes, date codes - including 2D, part numbers)
- Wire, Cable, and Connector Marking
- PC Board graphics
- Sequential Numbering
- Gaming pieces and cards
- Statements and forms
- Plastic cards

A UV Curing system should be thought of as consisting of *three* component parts, all integrally related:

• **The application**, particularly the end product it produces, will determine the requirements of the physical properties of the cured photochemistry

• **The photochemistry** is designed to achieve the *target properties* upon exposure to the appropriate energy of radiation.

• **The UV lamp system** will have a number of key exposure variables, which will also have a significant effect on the target properties. These key variables are spectral radiance (emitted wavelengths), irradiance (the "intensity" of UV arriving at the work surface), time of exposure, and the infrared energy directed toward the work surface. All of these must be optimized to achieve an efficient UV curing process with a sufficiently wide operating "window."

The principal ingredients of a UV-curable ink are:

Oligomers - Larger molecules; primarily determine ultimate physical properties.

Monomers - Smaller molecules; affect (wet) viscosity and rate of crosslinking reaction.

Photoinitiators - Respond to UV and initiate reaction; low concentration (1% - 2%).

Additives - Pigments, surfactants, de-foamers, etc. - these do not enter into the cross-linking reaction.

In addition to the chemistry of the UV-curable ink or coating, an important part of the UV system is the lamp system used to expose the materials to UV. UV curing begins with a photon-molecule collision. The effectiveness of the curing process is dependent on the ease or difficulty of projecting photons into a curable material to activate photoinitiator molecules.

The optical properties of the ink, such as optical density (opacity) and the optical characteristics of the curing lamp must be "matched" to produce an effective UV curing system.

A variety of photoinitiators is available to the formulators of inks and coatings. Each type of photoinitiator responds to a different – but very specific –wavelength range of UV. In examining the interaction of photons with photoinitiator molecules, we note an interesting and fundamental fact: *Photoinitiator molecules are dispersed uniformly throughout the material – but photons are not.*

Optically Thick Coatings and Inks

The reduction of UV energy as it passes into or through any material is described by the Beer-Lambert law. Energy that is not absorbed in an upper layer of the film and not reflected is transmitted and available to lower layers.

$$I_{a\lambda} = \frac{I_{o\lambda}(1 - 10^{-A_\lambda})}{d}$$

where I_o is the incident energy at wavelength λ, I_a is the energy absorbed, A_λ is absorbance at wavelength λ, and d is the depth from the surface or film thickness

An examination of this equation reveals the relative energy absorbed in the top surface and the extreme bottom of a film, as a function of absorbance. There is a great difference in the UV energy in these two zones.

Significance of Spectral Absorbance

In the typical spectral absorption for a photoinitiator, a pigment, and prepolymer, it is readily apparent that short UV wavelengths (200-300 nm) will be absorbed at the surface and not be available at all to lower depths. Typically, film thickness is limited, and adhesion to a substrate is often the first property to suffer. Even the photoinitiator absorbs energy in the wavelengths it is sensitive to, and blocks that same wavelength from deeper photoinitiator molecules. A photoinitiator that may be appropriate for a clear coating of for a thin film may not be an appropriate selection for an ink. For ink, a photoinitiator with a longer wavelength response would be a better choice.

Most UV curing involves *two* UV wavelength ranges at work simultaneously (*three*, if we include infra-red). Short wavelengths work on the surface; longer waves work more deeply in the ink or coating. This is principally the result of the fact that short wavelength energy is absorbed at the surface and is not available to deeper layers. Insufficient short-wave exposure may result in a tacky surface; insufficient long wavelength energy may result in adhesion failure. Each formulation and film thickness benefits from an appropriate ratio of short and long wavelength energy.

Key Elements of Exposure

There are a number of characteristics of the UV that affect the curing and the consequent performance of the UV curable material. The key elements of the UV exposure are:

A. ***UV Irradiance*** is the radiant power, within a stated wavelength range, arriving at a surface per unit area. It is photon flux, and is expressed in watts or milliwatts per square centimeter. The irradiance *profile* is a characteristic of the lamp geometry, power and focus, so does not vary with speed. ***Higher irradiance at the surface will provide correspondingly higher UV energy within the ink or coating.*** Depth of cure is more affected by irradiance than by length (time) of exposure (energy). The effects of irradiance are more important for higher absorbance (more opaque) films and inks.

B. ***Spectral Distribution*** describes the relative radiant energy as a function of wavelength emitted by a bulb or the wavelength distribution of radiant energy arriving at a surface. Radiance in wavelengths that do not activate photoinitiators becomes wasted energy in the form of heat. “H” bulbs are strongest in the 240-320 nm range; “D” bulbs in the 350-400 nm range, and “V” bulbs in the 400-450 nm range. All lamp manufacturers publish spectral distribution data for their bulbs.

C. ***UV Effective Energy*** is the radiant energy, within a stated wavelength range, arriving at a surface per unit area. Sometimes loosely (and incorrectly) referred to as “dose,” it is the total accumulated photon quantity arriving at a surface. Energy is inversely proportional to speed under any given exposure source, and is the time-integral of irradiance.

D. ***Infrared Radiance*** is the amount of infrared energy primarily emitted by the quartz envelope of the UV source. IR can be evaluated in energy or irradiance units, but usually the surface temperature it produces is of prime interest. The heat that it produces may be a benefit or a nuisance.

Conclusion

Most UV curable films are “optically thick,” and much more radiant energy is absorbed near the surface of the material, and absorbance varies wildly with wavelength. Spectral absorbance a critical factor in achieving a sufficiently wide process window. UV absorbance affects the depth of cure, and IR absorbance affects the observed temperature.

The effectiveness of a UV curing system is the practical result of a process design that combines the method of application of an ink or coating, the photochemistry of UV-curable inks, and the UV lamp designs into an integrated system. Careful attention to the optical factors and the interaction of inks and lamps can provide a successful UV system with wide operating limits.

Optical characteristics of lamp systems and their interaction with the optical properties of curable materials are an integral part of performance. Lamp characteristics, such as spectral distribution, peak irradiance, and controlled infrared energy can be effectively used, along with formulation strategies, to design UV systems with acceptably wide process windows.