Commercial applications of ultraviolet flexography on paper, foil, and plastic substrates

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Recent advances in inks, curing lamps, and printing presses make ultraviolet flexography a viable way to print on many substrates.

Six years ago ultraviolet flexography as a commercial printing process did not exist. Most development work in flexography was directed toward aqueous inks and coatings. The driving force behind these efforts were government environmental constraints. Within the last several years, progressive flexography converters have applied their craft to state-of-the-art ultraviolet curing technology and made ultraviolet flexography work. This paper presents the technical elements that allowed these advances.

Flexographic printing, when compared to other commercial printing processes, has a unique history. Flexography started as a low-cost printing process designed to place an identifying message on sacks and bags. For all purposes, the process was a rubber-plate letterpress system with a limited ink distribution system. Inks dried by solvent evaporation, and printing quality was readable. Flexography printers constantly worked toward higher quality and new markets, and they succeeded.

Today, flexography is a system that excels in printing plastic and foil substrates as well as competing in many areas of paper graphics. The commercial process today uses a limited ink distribution system which has been designed to utilize a finely etched roller and doctor blade to help control ink film thickness. This advantage is further enhanced by compressible plates and highly engineered presses. The pride of flexography printers in their craft has moved capabilities from "a little identification" to quality color reproductions.

Flexography and the environment

In the early '60s, California legislators directed their attention toward eliminating smog. They enacted several laws which set down guidelines for the control of solvent emissions into the atmosphere. In the past three decades, tremendous efforts have been made by government and manufacturers to improve air quality. There are two approaches to this problem. One is to incinerate the VOCs (volatile organic concentrations) from manufacturing air streams before discharge. This is not an energy-efficient way to clean the air stream. The other method is to use adhesives, inks, and coatings that do not contain VOCs. Radiation curing of 100% solids (no VOCs) ultraviolet inks is a very efficient approach. In flexography, water inks were the initial approach to the air pollution problem because they were commonplace in the industry. No-VOC water inks are a viable approach. Higher energy costs result only when drying ovens are used. However, it has been a technical struggle to formulate water inks with no VOCs and that have adhesion and alkali resistance on many plastic substrates. The use of ultraviolet inks has evolved slowly because it is a newer process.

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I. High-energy ultraviolet curing

Lamp	D300 W, m/s	D600 W, m/s
Black ultraviolet ink	0.90	3.60
Lamp	H300 W	H600 W
Black ultraviolet ink	0.60	2.50

Legal constraints and toxicity

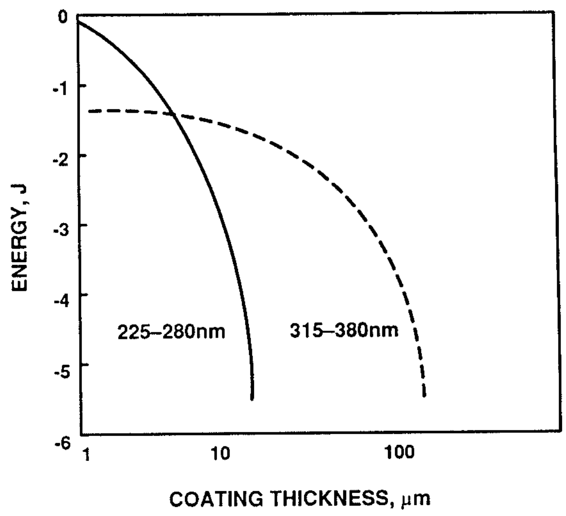
There is a dilemma regarding ultraviolet inks and the legal constraints imposed by the U.S. Environmental Protection Agency (EPA). On one hand, EPA holds high the 100% solids, no-VOC properties of ultraviolet curing systems. On the other hand, EPA has an arm-lock on oligomer manufacturers and converters to prevent contamination of the work place. Contamination of a worker with ultraviolet materials may result in allergenic reactions such as a skin rash.

As ultraviolet oligomer technology has evolved, responsible manufacturers and ink formulators have worked toward and attained products that are safe when used properly. To effectively serve and protect the workers in

II. Ultraviolet spectrum ink

Wavelength, nm	200		400
Energy/mole, kJ (6)	~500		~300
Ultraviolet ink		←Reactivity	
Ultraviolet ink		Penetration→	

1. Ultraviolet absorption bottom layer (1 μm)



this industry, it is important that EPA tap and utilize the technical knowledge of the radiation curing industry for the decision- and law-making processes. It is equally important that we as industry leaders insist on low-toxicity products and maintain high health and safety standards in our workplace.

Ultraviolet flexography

The driving force to use ultraviolet systems is low VOCs. Printers have pushed the process to a higher level of refinement to satisfy their markets. Presses have been equipped with fine, laser etched anilox rollers. Reverse doctor blades have been used and emphasis placed on high performance and make ready. The results are high print quality and good adhesion, gloss, and resistive properties. Exceptional white opacity has been attained with ultraviolet inks.

Rheology

In production, most rheology readings are made by cup or rotational viscosimeters. They are quick, down-and-dirty methods to attain standard conditions. These "viscosities" are inaccurate indications of the real printing rheology.

The printing rheology (rheology at the plate) is grossly affected by solvent evaporation in a conventional (solvent, water) ink system. The "viscosity" would be much higher on the plate than in the ink fountain where it is measured. Because there is no solvent to evaporate in the ultraviolet-curing flexography ink, the cup reading has an apparent viscosity much higher than a typical solvent system.

High-energy ultraviolet curing

Recent work with ultraviolet bulbs has created a technology with distinct advantages over lower powered systems.

Table I was generated from data presented at RadTech 90 (*1*). The fourfold increase in cure rate is phenomenal. This is a true breakthrough for the printer and converter.

To help use this new technology, let's address the "why" of this technical milestone. This topic is directly related to current printing and converting efficiency.

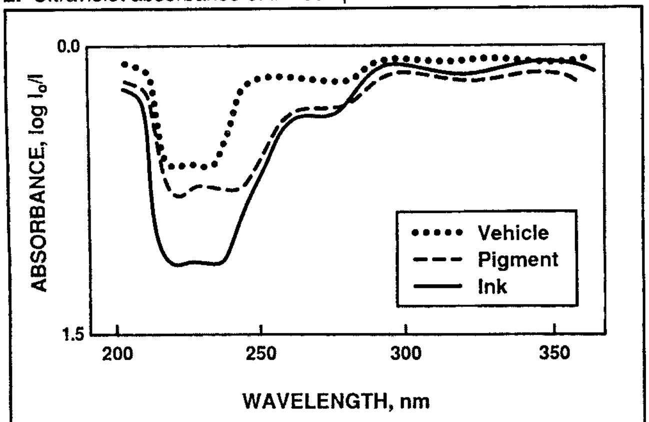
Ultraviolet light penetration

Recent innovations in ultraviolet radiation systems have resulted in great gains in curing efficiency (*1*). The gains are attributed to higher quality and quantity radiation for a specific ultraviolet system. Quality radiation is taken to mean optimum spectral distribution for a specific ultraviolet ink, ultraviolet adhesive, or ultraviolet coating. The optimum spectral distribution concept will be developed and focused upon in future work. To support this concept, we will draw upon some extraordinary publications dealing with the topic of radiation. The data will be presented in three distinct phases: general radiation, ultraviolet-lamp radiation distribution, and new ultraviolet-lamp efficiency. All of this data will be directed toward the idea of ultraviolet radiation with optimum spectral distribution.

Hawking (*2*) describes an electromagnetic spectra field as a finite system. In this finite system, the shorter wavelengths are characterized by quantum (energy packets) of lower amounts of total wave energy and high-energy-density packets. This energy spectra will account for the great penetrating capacity of short waves such as cosmic waves. The spectra also indicates a trend toward greater penetration and lower reactivity of longer wavelengths.

Table II is a comparison of short and long ultraviolet wavelengths. Within this small section of the electromag-

2. Ultraviolet absorbance of ink components



netic spectrum, great differences in specific wavelength penetration have been observed.

Another way to assess this phenomenon is to accept photon reactivity as the termination of a photon's penetration. Studies completed by Rubin (*3*) indicate that the longer wavelengths penetrate and induce curing deeper in an ultraviolet coating. This difference in reactivity penetration of specific wavelengths establishes that an optimum spectral distribution will exist for curing a specific film thickness.

Figure 1 was generated by mathematical analysis of an ultraviolet absorption model incorporating Beer-Lambert's Law. This law states, "The fraction of incident radiation absorbed is proportional to the number of absorbing molecules in its path." Spectral radiant power for an ultraviolet-normal lamp was taken from the literature (*4*).

Empirical data generated by experiments using a precise high-speed curing unit agreed with Fig. 1 with an accuracy of +2%. This heuristic graph defines the wavelength dependence of ultraviolet curing. Later in the paper, I'll use this work to predict ultraviolet-lamp cure efficiency.

Pigments generally reflect and block much of the ultraviolet light from going through the ink film. Inclusion of pigments that inhibit ultraviolet penetration will increase the apparent film thickness of an ink. This suggests that highly pigmented ultraviolet curing inks will be best served by high-intensity radiation at an optimum frequency.

The data in Fig. 1 indicate an approximate 50/50 distribution of energy about a 300-nm centerline. This energy distribution was estimated by analysis of the sum of continuum and line spectral radiant power in 5-nm bands for 200-300 nm and 300-400 nm (*4*). Pigmented ultraviolet inks cure much slower than clear ultraviolet coatings because of the blocking of the radiation by the pigments. In many cases, the ink is five times slower than the clear vehicle. In one sense, the ink is five times as thick. We may analyze that a more optimum ratio of energy distribution would produce a more effective cure of our "thick ink film." As an example, let's consider a 50-μm ink film thickness. Figure 1 indicates that at a $\cong$6-μm cure depth the high-frequency radiation falls off and the lower frequencies penetrate and cure the remaining 44 μm of ultraviolet ink. In this case, the 50-μm ultraviolet ink would respond more efficiently to a 12/88 distribution (high/low).

In Table I, extremely fast cures were exhibited by a high-intensity D600W bulb when curing a black offset ultraviolet ink. Equally astounding fast curing results were attained when curing a cationic coating with a H600W bulb. These two systems responded best (i.e., fastest cure) to high-energy radiation of different spectral distribution.

Windows and reflections

An effective method of enhancing ultraviolet curing is to select ink components that allow radiation of the active wavelengths of the photoinitiators. Formulating work suggests that the unobstructed radiation efficiently generates free radicals, and optimum levels of free radicals allow effective curing. **Figure 2** illustrates the effects of the different ultraviolet ink components upon ultraviolet radiation absorption.

The windows concept is to select pigments and vehicles that do not absorb energy in the same energy activity spectra as the specific photoinitiators used. The example above points out the profound effects of pigments on ultraviolet curing. Specific pigments such as carbon black and aluminum flake may decrease cure speed by a factor of 10 or more. Generally, pigment type and concentration are major factors in achieving higher press speeds. Very slight changes in color intensity will result in dramatic increases in cure speed.

Oligomers

Selection of oligomers is a means by which to control cure speed and influence adhesion. Curing oligomers have definite levels of sites which crosslink and cure.

A monofunctional oligomer has a site capable of joining two additional oligomers. A difunctional oligomer may join four oligomers, and a trifunctional oligomer may join six additional oligomers. The ability to crosslink enhances the solidification (curing) of the oligomer. In a pure mathematical sense, the combinations of the mono-, di-, and trifunctional entities would be 1, 6, and 15. The reciprocal of these numbers are suggested to be related to cure time.

To establish a practical empirical relationship between cure rate and oligomer functionality, an electron beam curing study was conducted. The neat oligomer was cured under vacuum to a 64 μm thickness. The exposure range for all of the oligomers tested was 2 J to 50 J.

The oligomers tested fell into three distinct groups:

1. Curing energy $>$50.0
2. Curing energy 5.1
3. Curing energy 2.5.

The study indicates a cure speed order related to functionality within a family of chemically similar oligomers. In a practical sense, higher functionality relates to faster press speeds.

Cationic systems

These systems, as the name implies, rely on acid to accelerate the curing. The unique element of ultraviolet cationic systems is the photoinitiator.

Radiation of the photoinitiator liberates an acid-catalyst which induces slower polymerization than a typical free radical ultraviolet-curing system. The benefit of this slower rate of reaction is less film stress and, in many cases, better adhesion. In production runs of cationic coatings, very high press speeds have been attained. Final curing and subsequent better resistive properties occurred in the roll for many hours.

Adhesion

Printers and converters are aware of and must overcome challenging adhesion problems to have a successful printing operation. To attain this success two major types of adhesion are addressed: soluble-chemical adhesion, which bites into and forms an amalgam with the substrate such as plastics and foil, and mechanical-physical adhesion, which is attained when ink flows through and co-mingles with a porous substrate (paper). The most critical type of adhesion for the converter is ink adhesion to nonporous substrates. There is a wide range of "ultraviolet-ink chemistry" available for adhesion to popular substrates in the marketplace.

Ultraviolet-adhesion problems which may be encountered by the converter are curing and substrate contamination. There is an optimum radiation level for maintaining adhesion in critical ink-substrate systems.

Substrate contamination may produce a weak boundary layer which will inhibit adhesion. This layer is more disastrous in printing operations because of the thin dimensions and high pigment volume of printing ink. In both cases, substrate-ink adhesion sites are successfully blocked by the weak boundary layer.

Special ultraviolet opacity effects

White ultraviolet ink prints with greater opacity than standard solvent inks. Converters have reported that the ultraviolet flexography whites attain opacity that approaches silk-screen printing. The reason for this increase in opacity is that the ultraviolet process uses the white pigment more effectively. Titanium dioxide pigment particles have the highest opacity when their diameters are one-half the wavelength of the reflective light and distributed evenly throughout the ink film (*5*). In volatile solvent systems, the explosive evaporation will disrupt the pigment particle distribution by extreme shrinking ($\cong$60%) and perhaps flocculation. The white ultraviolet ink, on the other hand, will shrink much less ($\cong$10%). Opacity is dependent upon each individual titanium dioxide particle bending photons to leave the ink film. Because of this phenomenon, the white ultraviolet ink has a pigment dispersion which is associated with greater opacity.

Conclusion

Ultraviolet flexography is a viable means to print many substrates. It offers good resistive properties and economical curing or drying. It is an acceptable solution to no VOCs. New equipment buyers should consider ultraviolet flexography.□

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