UV and Electron beam technology for printing and packaging applications

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Background

USE of radiant energy cured coatings dates back at least 4,000 years. Ancient Egyptians used a type of UV coating that cured when exposed to sunlight in preparing mummies. Also, an asphalt-based oil coating that polymerized upon exposure to solar radiation was used by ancient Egyptians as a sealant for ships.

In the modern era, scientific interest in developing UV/EB-cured systems began in the 1940s. At that time, the first patent was granted for an unsaturated polyester styrene printing ink that polymerized under UV exposure. One of the first attempts at applying UV/EB-cured systems to manufacturing was made in the late 1960s, but successful commercial application did not evolve until the early 1970s. The primary motivations for use of UV/EB-cured systems were and still are improved product performance and increased productivity.

Early applications of UV/EB-cured systems were limited to flat sheets, mainly in the wood products and printing industries. Starting in 1974, UV-curable inks and varnishes were used for decorating aluminum beverage cans. Improvements in plant engineering, such as rotating conveyors, multiple UV sources and adjustments to curing equipment, have allowed three-dimensional (3D) applications of UV/EB-cured materials. In addition, advances in polymer science have provided a wide variety of UV/EB-cured materials that can exhibit characteristics required by the end-user in specific applications.

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Introduction

In this time of rapid change in technology, manufacturers are examining processes which are environmentally friendly, cost effective, and energy efficient. One such technology that has become more popular and more economically feasible around the world is Ultraviolet (UV) and Electron Beam (EB) curing technology. Among experts, UV and EB ink curing have been discussed in the same conversation as the terms sustainable, flexible manufacturing, energy efficiency, increased ROI, higher quality products, lower greenhouse gas and VOC emissions.

Before divulging the world of radiation technology, it is important to understand the basic process. UV and EB curing technology is often referred to as radiation curing 'radcure' because both systems use radiant energy sources: ultraviolet rays and electron beams. Radiation curing is typically described as ultraviolet light and electron beams polymerizing a combination of monomers and oligomers in the form of ink into a substrate.

Radiation curing and UV/EB inks have been around since the 1960s. However, they have only recently become widely accepted, they are therefore still considered 'new' technology. Most conventional ink systems need to go through a drying process by either absorbing or evaporating excessive ink and solvent or water, or a combination of both. UV/EB inks go through a different process called 'curing' which is a chemical reaction that a material goes through to get from the wet to the dry stage. Ultraviolet and electron beam cure via different modes of energy and ink compositions.

Conventional coatings, inks and adhesives

Conventional oil/solvent based and waterborne coatings, inks and adhesives are evaporative systems. They use suitable partially pre-polymerized monomers (alkyd, acrylic, epoxy, silicone, etc.) and pigments dispersed in a solvent. These pre-polymers must further polymerize and cross-link during the cure to become solids. For lacquers, solvent can be much more than half of the final volume of coating as applied. Lacquers simply solidify upon evaporation of the solvent. They are more fully polymerized during their manufacture then other conventional coatings and no further polymerization is needed when they are applied. However, there is no crosslinking and they melt or mar easily. They shrink from loss of solvent and not because of further polymerization. Heat is used to evaporate organic solvent or water and to accelerate polymerization.

UV / EB and flexible packaging

There is also growing interest in UV/EB technology for flexible packaging. The growth in UV/EB applications is due, in part, from the inherent advantages over solvent- and water-based materials. The solvent in conventional inks, coatings and adhesives functions simply as the "carrier" for the "solids" portion of the material. In most cases, solvent emissions are handled by thermal oxidation which produces greenhouse gas (CO_2). Solvents are highly refined materials derived from fossil hydrocarbon sources. It is quite wasteful to use such a high-value material for such a low-value temporary function. Solvent-based materials are old technology that is clearly out of step with a sustainable future.

At first glance, water-based inks, coatings and adhesives would appear to be an excellent choice from an environmental perspective. Water is a relatively plentiful, low cost and environmentally friendly carrier. The main disadvantage with water is the high energy required to remove water from the solids portion of the formula. This high-energy requirement for water is illustrated by comparing the heat of vaporization to some common solvents.

water = 540 calories/gram
toluene = 88 calories/gram
heptane = 76 calories/gram

The generation of energy needed to operate the driers to remove water results in significant CO_2 emissions. In addition, most water-based materials do contain some solvents to aid the formation of the polymer film upon drying the ink, coating or adhesive. Also, in many cases, water-based materials do not have the resistance or appearance properties to match higher performance solvent- or UV/EB-based materials.

In spite of the clear advantages of UV/EB technology over solvent and water-based technology, there is often some confusion as to whether UV or EB is a better choice. A clear understanding of the differences between UV and EB can facilitate a selection of which technology is best suited to the end-use application.

Technology

UV energy considerations

There are some fundamental differences between UV and EB energy that provide the foundation for understanding the technologies. The smallest "bit" of UV energy is the photon that is known to have both particle and wave-like characteristics. The energy for photons is determined by the wavelength. The range of wavelengths for UV curing applications is typically about 250 to 450 nm. The shorter the wavelength, the higher the energy. Wavelength units may be converted to other energy units for comparison. For example, a 350 nm photon is equivalent to 3.5 electron volts (eV). UVcuring processes are often characterized by the total amount of applied UV energy impinging per unit surface area (also known as the irradiance). The UV energy needed for a curing process depends on the material and the application. For an ink, coating or adhesive for a packaging application, the UV energy typically ranges from about 0.1 to 0.5 J/cm^2.

EB energy considerations

The smallest 'bit' of EB energy is the electron. The energy of the electrons is determined by the accelerating potential of the EB equipment. The range of accelerating potential used for typical packaging applications is about 80 to 180 kV. The electrons lose some energy when passing through the foil window and the air space between the window and the substrate. For example, the electrons from an EB unit operating at 100 kV have an average energy of about 70 keV when they reach the substrate. EB curing processes are often characterized by the total amount of energy absorbed per unit mass of the substrate (also known as the cure dose). The dose for EB curing depends on the material and the application. For an ink, coating or adhesive for a packaging application, the cure dose typically ranges from about 20 to 40 kGy (2 to 4 Mrads).

UV / EB energy comparison

It is interesting to compare the energy of a typical UV photon (3.5 eV) to an EB electron (70,000 eV). Clearly, EB electrons are much more energetic than UV photons. This has a significant impact on how this energy interacts with the media to be cured. The typical chemical bond energy in an organic material that is the basis of an ink, coating or adhesive is on the order of 5 eV. Curing reactions are initiated with the breaking of a chemical bond. Since UV photons have less energy than the bond energy, they cannot initiate curing on their own. A photoinitiator is needed which can be activated by the lower energy photons. The energy of the EB electrons easily exceeds the bond energy of the curable materials; thus they will initiate curing without an added photoinitiator. EB is also known as ionizing radiation because of its ability to break chemical bonds. UV is non-ionizing radiation.

UV curing is characterized by the energy absorbed per unit area (irradiance), while EB curing is characterized by the energy per unit mass (dose).

If one considers a given thickness and density of the substrate, it is possible to make a direct comparison of the total applied energy in UV- and EB-curing processes. A typical modern low voltage EB unit operating at 125 kV will penetrate into a 50 g/m^2 layer.

Thus, given 1 kGy = 1 J/gram, and assuming a 50 gram/m^2 substrate, then; 20 to 40 kGy = 0.1 to 0.2 J/cm^2 for typical EB curing compared to: 0.1 to 0.5 J/cm^2 for typical UV curing.

The lesson from this exercise in energy unit conversions is that although EB electrons are much more energetic than UV photons, the total amount of energy applied in a typical curing process is not all that different.

UV and EB penetration

The nature of the energy determines how it penetrates into a material. Curing can only occur in areas that are effectively exposed. *Figure 1* provides a cross-sectional illustration of the differences between UV and EB penetration. Penetration of UV energy depends on the optical density (OD) of the material. Clear materials are "optically thin." In general, UV energy can easily penetrate clear materials such as overprint coatings and

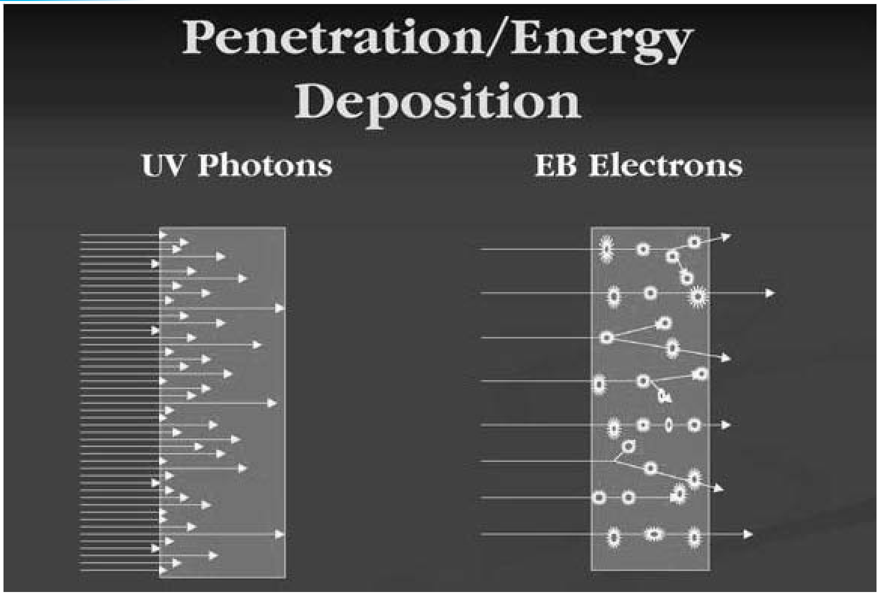

Fig. 1: Penetration of UV and EB Energy

clear films.

Even if a portion of the UV spectrum is blocked by a clear layer (such as a PET film), effective curing can usually be achieved throughout the thickness of the layer by selecting the proper photoinitiator package. Penetration of UV energy becomes a significant challenge when curing 'optically thick' pigmented materials. Many pigmented printing inks can be UV cured as long as the pigment loading and/or ink thicknesses remain relatively low. It is typically difficult to UV cure through printed, white opaque, heavy black or metallic inks.

EB penetration depends upon the mass density and thickness of the material. Electrons penetrate more deeply through lower density materials (such as polyolefin films and paper) compared to high-density materials such as metal foils. Mass density and thickness taken together may be expressed as the basis weight of the material. For most printing and packaging applications, the basis weight is expressed in units of grams/ meter 2 or pounds/3000 ft^2. Electrons are "color blind" and penetration is not affected by pigments and opaque substrates. EB is ideal for curing high opacity white, black and metallic ink layers. EB can also penetrate reverse printed, metalized and white films as well as papers to instantly cure adhesive layers for laminating applications.
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UV and EB Equipment

The most common UV equipment for printing and packaging applications is based on medium-pressure mercury lamps. These lamps may be energized through electrodes (arc type) or by microwaves (electrodeless). Medium pressure mercury lamps produce a characteristic UV-emission spectrum with multiple peaks between 250 nm to 450 nm. Mercury lamps may also be doped with various elements to shift the spectral output to better match the inks, coating or adhesive that is being cured.

Interstation installation allows curing of each ink color. Multiple colors are combined in a 'dry trapping' process to create the graphic image. Interstation curing also allows press designs in which the printed side of the web may be turned up against an idler roll between stations.

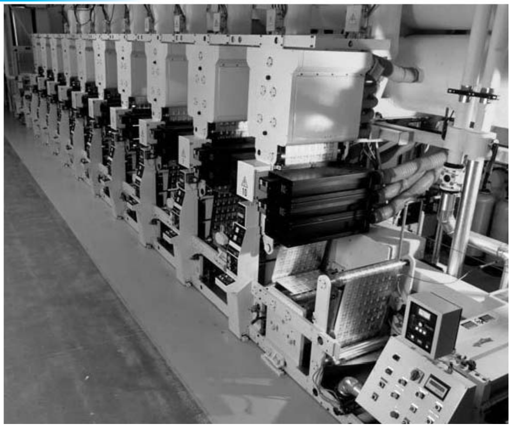

Fig 2: Interstation UV installation on a Flexo Press

EB equipment is based on electrically operated filaments and grids contained within a vacuum chamber. The electrons are accelerated through a window/foil structure to reach the substrate at atmospheric pressure. EB equipment includes "curtain" and scanning type units. The curtain type is used almost exclusively for printing and packaging applications. Most EB equipment includes an active pumping system to maintain a vacuum in the electron gun chamber. A new generation of modular 10- and 16-inch wide EB equipment based on permanent vacuum emitters is also now available.

Original industrial EB equipment was quite large. Modern low-voltage EB equipment can be less than one-half the size of original industrial EB equipment. The development of modern low-voltage EB equipment coincides nicely with the development of web offset presses incorporating variable repeat length technology. This has facilitated expansion of web-offset printing technology beyond folding cartons to flexible packaging and labels.

Both UV and EB equipment are very safe to operate and there are no significant drivers for selection of one technology over the other based on safety.

Recently new technology (Wetflex) has been developed to wet trap flexographic inks. Wet trapping allows interstation curing to be eliminated and replaced with a single EB curing station at the end of the press. This technology has also been shown to give extremely low dot gain which results in

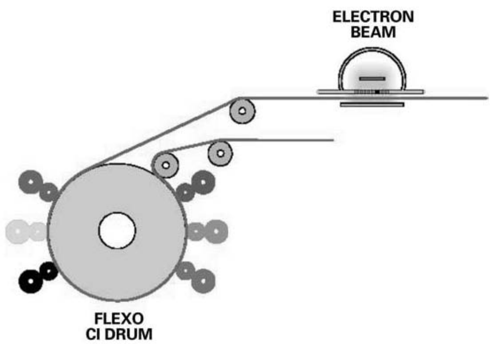

Fig. 3: WetFlex EB flexographic printing

superior quality printing. It should be noted that Wetflex is limited to central impression (CI) flexo press configurations in which the printed side of the web does not contact idler rolls until after EB curing. Flexographic CI printing is often the preferred method for flexible packaging since it provides superior handling of extensible film substrates. New permanent vacuum modular low-voltage equipment makes it possible to consider interstation EB curing. So far this does not appear to be a commercial reality, but it is an area for potential future development.

Capital & operating costs

Even though a single UV lamp is significantly lower in cost than an EB unit, when one considers the total capital cost of a wide, high-speed line, EB may be comparable or lower in cost than a multilamp UV installation.

One of the primary advantages of UV and EB curing is the reduced energy costs compared to thermal drying ovens. Another major component of the operating expense is the cost of the inks, coatings and adhesives. When comparisons are made based on the solids that are applied, it may be seen that the cost of UV/EB materials (which are near 100% solids) may not command a significant premium.

In general, there does not tend to be a significant difference in cost between UV and EB inks, coatings and adhesives for printing and packaging applications. This may be due in part to a declining cost of photoinitiators following the expiration of some key patents. Comparison of UV and EB operating costs is, therefore, more related to the equipment itself. With mercury-based UV lamps, about one-half of the electrical energy input is converted to UV energy. The remaining energy is lost as heat. Some additional electrical energy is consumed in the operation of blowers for air cooling which is most common for printing and packaging applications.

EB equipment is more efficient at converting electrical energy into curing energy compared to UV equipment. Some additional electrical energy is needed for vacuum pumps and water cooling of the emitter. Another operating cost of EB is nitrogen, which is needed to inert the curing zone for most ink and coating applications.

A detailed comparison of operating costs for UV and EB can be made for a specific application. Often, this analysis will show similar costs for UV and EBand significant savings compared to thermal curing.

Food packaging

UV-curable coatings and inks have been used in food packaging applications for many years. These applications are possible with packaging designs that include a functional barrier between the ink or coating and the food. Paint and odor problems can usually be prevented by using properly formulated UV-curable inks and coatings. Photoinitiators and photoinitiator fragments can be a source of concern for migration, odor and taint. New systems have been developed that include polymeric photointiators, reactive photointiators, and oligomers that contain a 'built-in' photoinitiator moiety. Some of these systems have been effective but may still lack cost/ performance properties needed for practical applications.

Since EB does not require an initiator, it is often considered to be more "food friendly." EB-induced breakdown of components of inks, coatings, adhesives and substrates may be a source of other taint, odor and migration issues that merit investigation for a given application. In many packaging constructions, the functional barrier is obvious and there is no reasonable expectation of adulterating the food. Examples include labels on rigid containers and folding cartons that have an additional inner layer of packaging around the food.

There are many constructions in which the barrier is less obvious. This may include cases in which a relatively thin polyolefin film is the only layer between the UV/EB material and the food. It may also include applications in which the UV/EB printed/coated surface is in contact with the food contact surface during roll-to-roll or cut-and-stack processing of the packaging allowing off-setting to occur prior to filling.

Conclusions

UV and EB are environmentally sound technologies well suited for printing and packaging applications. The selection of UV or EB should be based on the best fit for the selected application. For some applications the choice is obvious. Others may require a cost/benefit analysis in order to make the best choice.

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