Wood Coating with UV-LED Curing: A Focus on Heat

By Ed Kiyoi

Light-emitting diodes for ultraviolet curing applications (UV-LEDs) have been commercially available for more than a decade. However, their unique output characteristics work best with newly formulated UV chemistries that take advantage of UV-LEDs' many benefits. Initially, UV-LEDs were used in applications such as medical device assembly and inkjet printing, but, with increasing energy outputs and lower initial costs, wood-coating applications became commercially viable. Coating heat-sensitive wood substrates is especially challenging, but recent testing shows that UV-LEDs provide a significant advantage. This paper discusses the characteristics and benefits of UV-LED curing systems for wood coating applications, including recent temperature test comparisons, and reviews formulating strategies for optimizing the performance of UV-LED systems.

UV-LED Lamp Characteristics

As electrons move through a semiconductor device (called a diode), it emits energy in the form of photons. The specific materials in the diode determine the photon wavelengths and, in the case of UV-LEDs, the output is typically in a very narrow band +/- 10nm. Figure 1 compares

FIGURE 1

Wavelength output comparison of traditional UV and UV-LED Lamps

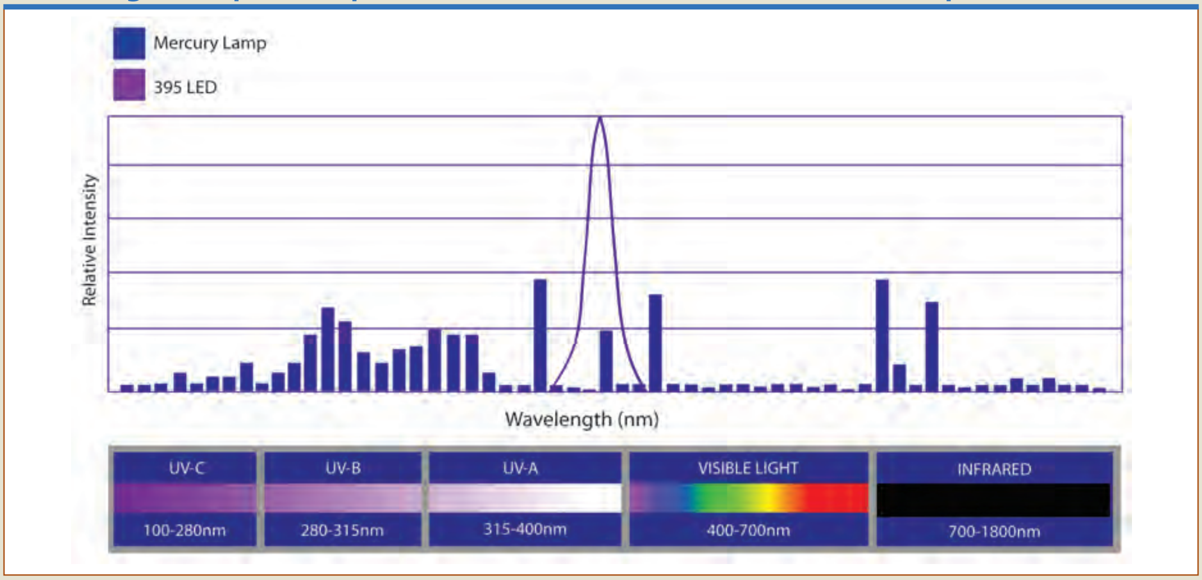


FIGURE 2

UV-curing photopolymerization process

the output of a 395nm UV-LED lamp with a typical traditional UV lamp. It is important to note the difference in irradiance and wavelength of the output, both are key to understanding a UV curing process.

The UV Curing Process

UV curing is a photopolymerization process that uses UV energy to change a liquid to a solid. Upon absorption of the UV energy (as shown in Figure 2), the photoinitiator (PI) produces free-radicals which initiate crosslinking with binders (monomers and oligomers) in a polymerization reaction to cure or solidify the wood coating. UV formulations also incorporate various additives such as stabilizers, wetting agents, adhesion promoters, defoamers and pigments to provide desirable characteristics or color of the cured material.

UV-LED Curing Benefits for Wood Coating Operations

Figure 3 highlights the overall advantages for UV-LED curing in wood applications. The electrical to optical conversion efficiency of UV-LEDs is much better, plus the instant on/off and no warm-up time results in a combined savings of 70% on electricity. They are a cool source largely due to no output in the infrared range. This reduced heat eliminates complicated cooling mechanisms such as cooling air (quieter operation) and external shutters, and enables applications on heat-sensitive wood substrates such as glued veneers and resinous woods.

UV-LED Wood Coating Applications

Taking a deeper dive into wood coating lines, a significant challenge is the heat generated throughout the process. Heat is particularly challenging for resinous/oily woods such as pine, fir, spruce and mahogany. When a resinous wood becomes too hot, the resins or pitch come to the surface or "bleed," causing problems with coating adhesion and discoloration. See Figure 4.

Properly drying resinous wood is an important factor for successful UV coating. During kiln drying of pine, a special procedure is used to set the pitch (71-77°C) to help prevent bleeding during coating operations.[1] Also, for best results, moisture content

FIGURE 3

UV-LED curing benefits and features

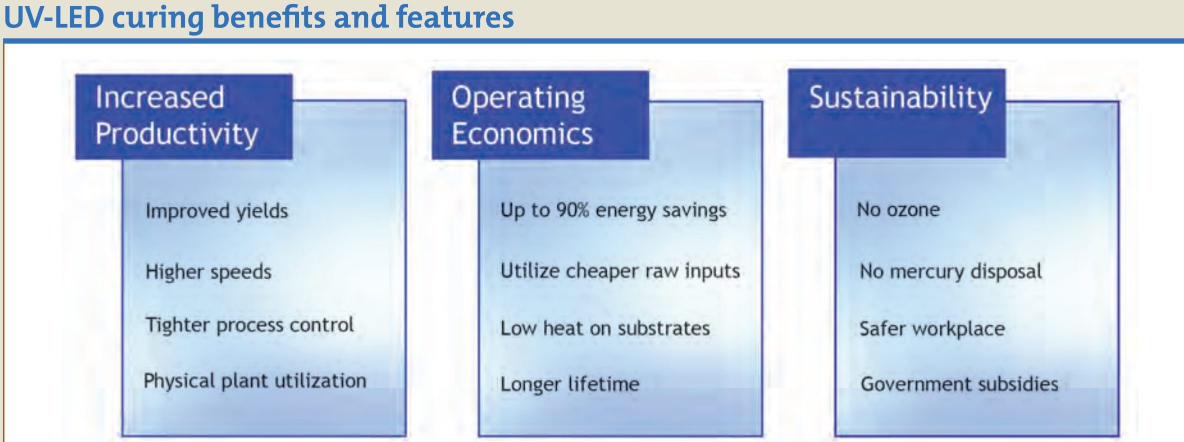
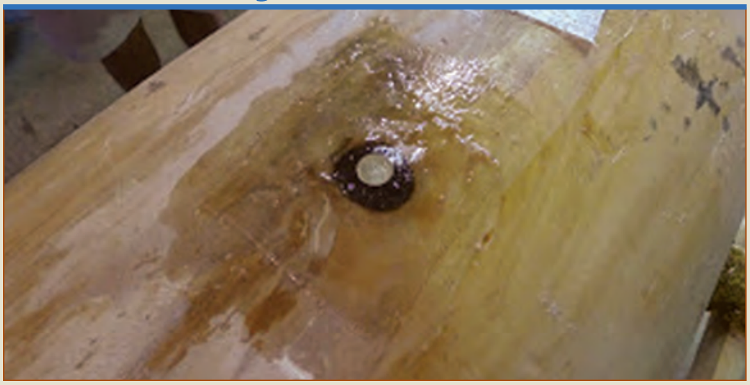


Figure 4

Resin bleed damage



impact on the substrate/work piece temperature. Testing has shown that the UV-LED curing lamps utilizing optimized coatings increase the work piece temperature from 20°C to 29°C (45% increase) after 10 passes, while traditional methods increase that same work piece from 20°C to 60°C (200% increase). See Figure 5. This is due to two factors. First, UV-LEDs emit no infrared energy which is the largest contributor to the heat increase. Second, UV-LED energy is concentrated in a small tight region (see Figure 1 again) and properly formulated coatings take advantage of the tight energy band, utilizing it all

should be about 6-8% and certainly not above 12%. The inconsistencies of wood products from pallet to pallet and even board to board, make it desirable to find a lower temperature UV-curing solution that will enable consistent finishing and coating results, and possibly enable the use of less costly, lower grade woods.

If utilizing a traditional mercury lamp, heat in the form of UV energy as well as infrared energy (IR) can be seen in three separate ways:

1. **Work Piece**—Heat is delivered directly from a curing system as it passes under a UV lamp.
2. **Conveyor**—As the work pieces do not fully cover the conveyor, energy not used to cure the work piece is then absorbed by the conveyor that will later transfer a portion of that stored heat onto the next work piece placed above the conveyor location.
3. **Stack**—At the end of a coating line, the work pieces are stacked. Heat is trapped between pieces as they wait to either be coated on the other side or placed into storage.

Work Piece Heat

A typical coating line can range from six curing stations up to 10. Each curing station will have an

Figure 5

Surface temperature testing results

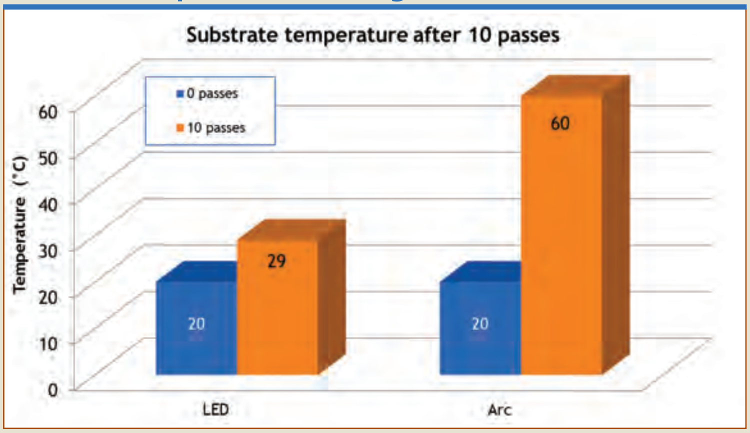


Figure 6

Surface temperature and conveyor heat

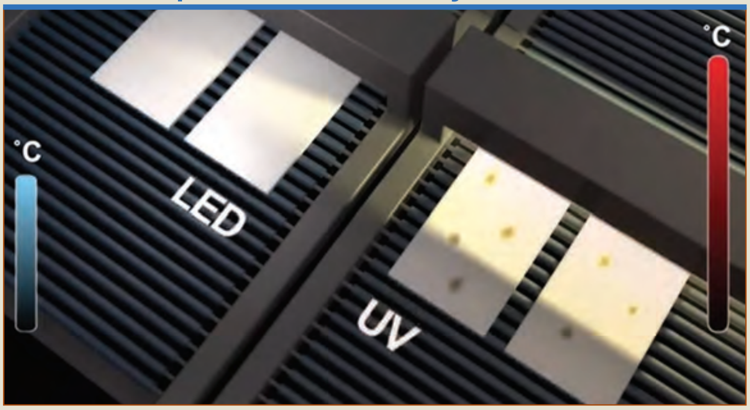
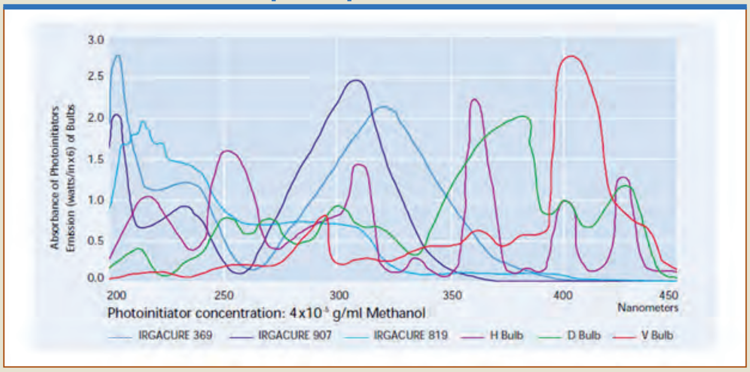


Image courtesy of Sherwin-Williams

Figure 7

Photoinitiator spectral absorbance compared to traditional UV lamp output



in the photopolymerization process without any extra or unwanted wavelengths.

Conveyor Heat

Another important result was the significant decrease seen in the surface temperature of the conveyor belt. After the first pass through the coating line, the boards are flipped over and run through again to coat the second side. This means the first side, which is already coated, is in direct contact with the hot conveyor causing damage to the already coated pine boards. With UV-LED lamps, the conveyor does not increase in heat, a savings of up to 30°C over traditional methods.

Formulating UV Chemistries for UV-LED Lamps

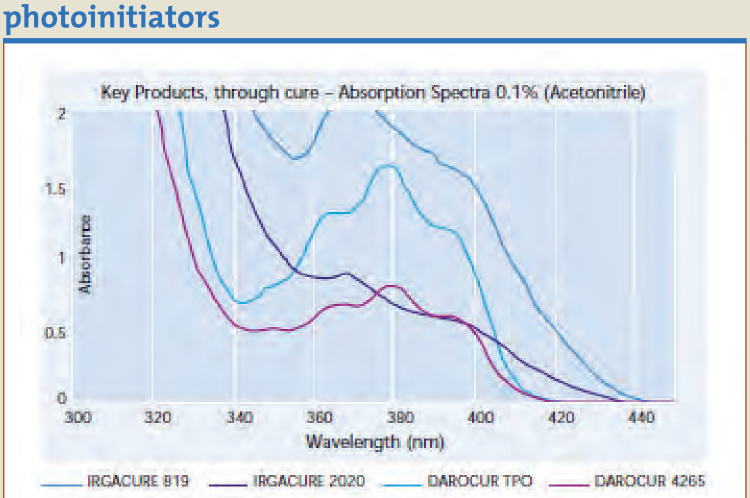
For efficient and effective UV curing of a coating, the formulator seeks to overlap the UV lamp output with the spectral absorption of the PI. The amount of PI in a typical UV formulation is usually very small, less than 5%. PIs typically absorb across a range of wavelengths, not a narrow band. For example, Figure 6 shows the spectral absorption for different PIs and the wavelength output for traditional UV lamps. Many existing UV formulations developed for curing with a typical UV lamp (shown as H-bulb) use a broad spectrum PI. While there is often some absorption within the UV-LED output range, it is clear to see that much of the PI absorption range is wasted. A more efficient cure is possible with a formulation designed specifically for UV-LED curing using a PI with more concentrated absorption in the UV-A range such as those shown in Figure 7.

The monomers in the formulation serve as the reactive diluent enabling the formulator to control viscosity for proper application (spraying, rolling, etc.) of the uncured material. Rather than volatilizing, as is typical with conventional formulations, the monomer reacts and becomes part of the UV-cured material. The oligomers (and their backbone structure) determine the overall properties of the material.

The longer wavelength output, such as the UV-A range seen from UV-LEDs, penetrates through thick and pigmented systems producing through-cure of the material that ensures surface adhesion and the ability to cure thicker pigmented wood coatings. Short wavelength output (200-280nm) is unable to penetrate very far into a material, but provides surface curing. See Figure 8.

Figure 8

Examples of longer wavelength absorption photoinitiators



Overcoming Surface Cure Issues

Surface curing is important for wood coating applications because it determines properties such as scratch and chemical resistance which are important for furniture and cabinetry applications. Improper surface curing due to oxygen inhibition was often an issue for UV-LED curing, but has largely been overcome by various means. Of course, curing in an inert (nitrogen) atmosphere is one option, but adds cost and complexity to the system. Another option is to add oxygen-consuming or scavenging compounds such as amines or aminoacrylates to overcome oxygen inhibition.[3]

Research has indicated that peak irradiance (W/cm^2) and total UV-A energy (mJ/ cm^2) delivered are more important than a precise wavelength match on formulations developed to cure in the UV-A region. Peak irradiance is an important metric since irradiance is required to initiate the polymerization. Higher peak irradiance (such as that found in UV-LEDs) results in a more aggressive polymerization mechanism helping to overcome oxygen inhibition at the surface and achieving the required cure rate.[4]

More recently it has been shown that higher functional oligomers can also minimize the oxygen inhibition, thereby improving surface curing. Commercially, a mercapto-modified polyester acrylate resin is available that replaces a portion of the oligomer in a UV formulation to improve surface curing under UV-LED lamps. This co-resin is compatible with urethane acrylates, some epoxy and polyester acrylates, and acidic adhesion promoters; and typically accounts for 20-40% of the formulation by weight. Mono- (MAPO) and bisacylphospineoxides (BAPO) are recommended photoinitiator types for UV-LED curing. There are a variety of commercial examples available.[5]

In September 2012, Eileen Jaranilla-Tran with the Rahn-Group reported on her investigation of overprint varnishes (OPV), flexographic inks and ink jet inks. She found that Norrish Type I PIs such as BAPO are effective to achieve good surface cure and preferable to TPO and BDMM (especially when combined with highly reactive acrylate oligomers and they minimize yellowing). ITX (Type II) was more reactive, but caused too much yellowing for OPV and white inks. She also noted that pigment selection is key because pigments compete with the PI for UV energy.[6] Although this testing was done using varnishes and inks for printing applications, these findings have implications for formulators of wood coatings as well.

Gloss Control

As is common with UV coatings in general, achieving lower gloss has been an issue when applying thick pigmented layers (>15g/m^2) via roll coating or with spray application (rarely used). It has been observed that higher temperatures just prior to topcoat application results in lower gloss. For example, using a combination of arc lamps and then UV-LED can produce satin finishes (30-40 gloss). Gloss control is not an issue for thinner topcoats.

UV-LED curing offers many economic and environmental advantages to wood coating end-users and growth opportunities for formulators. These tests demonstrated lower substrate temperatures during UV-LED curing of coatings. UV-LEDs expand the capability of wood finishers to more cost-effectively coat heat-sensitive substrates such as glued veneers and resinous woods such as pine. Coating formulators have the opportunity to expand their market by formulating coatings specifically for UV-LED wood coatings as this market grows. End-users have a choice of arc, LED or even a combination of both, thus providing more flexibility to better control production parameters along with the option to coat heat-sensitive substrates on their existing lines. Wood coating lines that already have traditional UV installed, but have heat problems, can retrofit the line with LED in several positions to reduce temperatures and utilize traditional lamps for special performance characteristics.

Conclusions

- UV-LED lamps offer significant advantages over traditional UV lamps for wood finishing, including less space, monitoring, maintenance and downtime which translates into higher productivity rates, less scrap and higher quality end products at lower costs.
- The use of traditional UV lamps to cure coatings on heat-sensitive substrates such as glued veneers and resinous woods (such as pine) causes damage to the substrate and increases scrap rates. UV-LEDs produce significantly less heat, enabling coating of heat-sensitive wood substrates.
- Test results showed significantly lower surface temperatures of pine boards when cured with UV-LED lamps as compared to traditional lamps. The UV-LED lamps kept the pine board surface temperature 8°C lower and the conveyor surface temperature 30°C lower than the traditional lamps.
- Formulating chemistries for UV-LED presents challenges due to the narrow wavelength output in the UV-A range. Previous research showed that peak irradiance and total UV-A energy delivered are more important than a precise wavelength match because high peak irradiance results in more aggressive polymerization, thus helping to overcome oxygen inhibition at the surface.
- Gloss control is not an issue on thin topcoats, but typically

a temperature boost from a traditional UV or an infrared lamp causes lower gloss on thicker pigmented coatings.

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