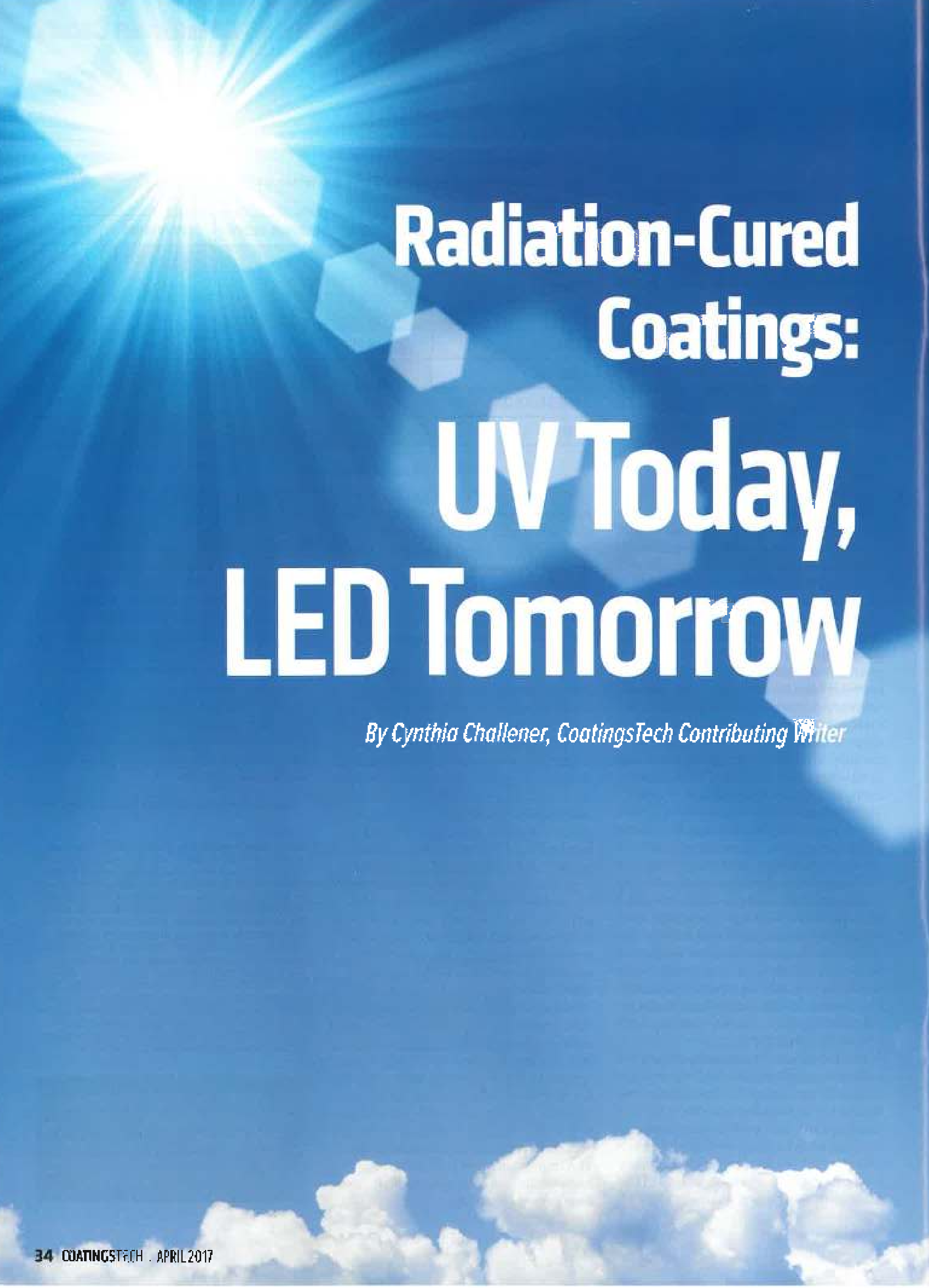

Radiation-Cured Coatings: UV Today, LED Tomorrow

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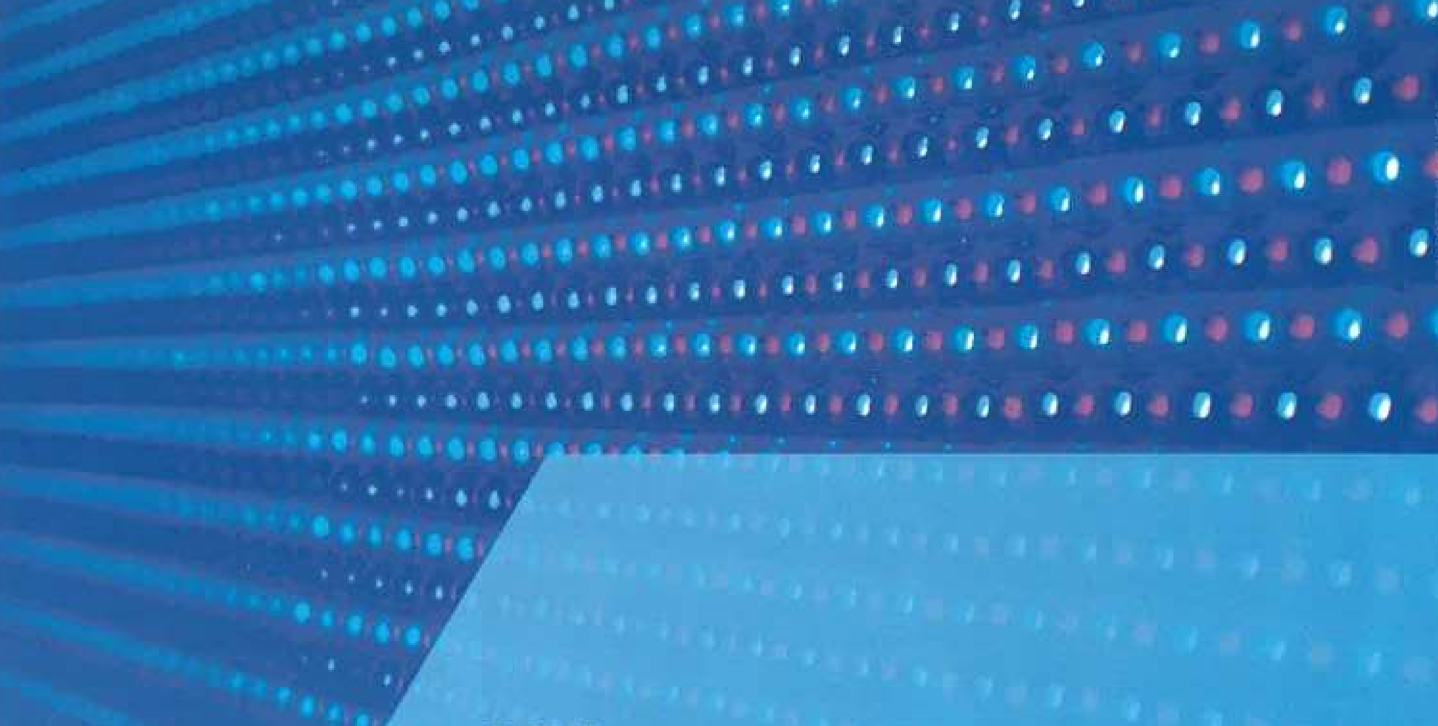

Where radiation-cured coatings are employed, ultraviolet (UV)-curable systems predominate, and current development efforts are largely focused on improving waterborne systems and reducing the impacts of monomers (via migration) and photoinitiators (as residual impurities). Looking to the future, LED curing is generating significant interest and excitement, particularly as curing equipment and coating formulations improve.

In applications where their use is practical, radiation-curable coatings offer numerous advantages over thermally cured systems, including smaller manufacturing footprints, reduced energy consumption, reduced environmental impacts, and faster curing times, which often translate to faster line speeds. As recently as 2015, however, UV- and electron beam (EB)-cured coatings only accounted for 2% of the global industrial coatings market, according to IHS. The high costs of the raw materials compared to conventional coatings combined with the need to install specialized application equipment are two key hindrances to wider adoption. In addition, radiation curing of complex shapes and large objects is challenging, and thus this technology is not typically considered for these types of applications. Western Europe is the largest geographical market, followed closely by North America and China.

In 2016, 12–13 million formulated gallons worth $640 million were sold in North America, according to market research firm Nerlfi, Kusumgar & Growney (KNG). UV-cured systems represented approximately 88–90% of the total sales. Graphic arts as the largest end use by far accounted for 45–50% of the market, but is experiencing minimal growth of 1% per year. Prefinished wood products, which include wood flooring and wood furniture and fixtures, each accounted for approximately 11% of the market for radiation-cured coatings and are growing at much healthier annual rates of 5% and 6%, respectively. The other major application is release liners (e.g., labels), which accounted for 8.5% of the market; demand in this sector is growing at 11% per year. There are numerous other minor applications, including optical fibers, vinyl flooring, consumer electronics, automotive plastic components, metal packaging, and special purpose uses such as nail polish, medical implants, and field-applied floor coatings. Most radiation-cured coatings are based on acrylate resins, although cationic epoxy, epoxy silane, and unsaturated polyester formulations are used in small quantities.

State of the Market

Interest in UV-cured coatings continues to expand, particularly for heat-sensitive substrates such as plastics or wood. Kevin Joesel, director of Sales in the Americas for Heraeus Noblelight America expects growth in plastic coatings as more composites and thermoplastic materials are used for lightweighting of vehicles. He also notes that the market for UV-curable coatings on wood continues to show strength, and UV coatings for metal, while a small percentage of the market, have started to show life once again. In addition, UV technology for coatings and adhesives for electronics applications is ubiquitous, according to Joesel. "As high-tech companies continue to move into traditional industries, they are very comfortable applying technologies they have been using for years in these legacy industries," he notes.

Over the last decade, radiation-cured coatings have become an important technology for wood and furniture coatings, according to Marcel Krohnen, global head of End Use Wood & Furniture Coatings at BYK-Chemie GmbH. "Considering all available technologies (solventborne, waterborne, radiation cured, powder and their sub segments) and are exhibiting the strongest growth worldwide when compared to other technologies (solventborne, waterborne, powder)," he adds. Dual cure and electron-beam coatings are of interest only in very niche applications. Overall growth of 5–8 % is expected for UV-curable wood coatings for the next few years, according to Teresa M. Donahue, senior research and development project leader for Van Technologies, Inc.

In the wood sector, 100% UV-cured coatings cured using arc-lamps is standard coating technology for flooring and flat panel OEM substrates, according to Anthony Woods, Global Research, Development and Innovation, director with AkzoNobel Wood Coatings. Spray applied technologies, on the other hand, tend to use either water-based or solventborne rather than 100% UV systems due to the environmental, health, and safety concerns associated with spraying low molecular weight oligomers, as well as the difficulties often encountered with respect to achieving effective curing. Within the building products and kitchen cabinet segments in Europe and North America in particular, AkzoNobel is seeing growth in waterborne UV technology. Electron-beam technology is not commonly used with wood coatings, although Woods does point to some segments, such as interior doors and edge-banding, where EB curing finds niche applications.

UV curing via microwave or arc-generated mercury vapor lamps is also well established for metal packaging, with approximately 40% of all printing inks being applied in this manner, according to Ian Lewis, solution lab manager–Inks with AkzoNobel Metal Coatings. "Thermally cured primers are normally still required for most can types, but the use of epoxide (cationic UV cure) and acrylate UV technologies is growing for protective OPV layers (perhaps 5%), often in-line over the printing inks, resulting in much more efficient manufacture—saving cost and reducing lead times," he adds. At present, EB curing is not proven viable commercially, but remains interesting as a concept, particularly for the generation of primers and single coatings in coil applications, according to Lewis.

In addition to wood and direct-to-metal applications, Van Technologies receives numerous inquiries for a variety of other applications for UV-cured coatings, including plastic, fiberglass, and ceramic substrates. "Coating end-users are investigating the potential for the use of UV-curable coatings in their respective markets, and many of these inquiries have been directed at exterior applications," notes Donahue.

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The Growth of LED Curing

While conventional UV curing remains the leading technology, LED curing is growing rapidly and creating excitement in the market. Suppliers have developed LED systems that offer thermal management techniques to remove excess heat from the system while providing a consistent operating temperature for the diodes to function at maximum performance over their operating lifetime of greater than 20,000 hours, according to Joe Becker, a product manager with Phoseon Technology, a manufacturer of LED-curing equipment. LED-curing units also support trouble-free press operation with no warm-up time required and less down time due to the instant on/off capability. Maintenance is also minimal due to the lack of moving parts, according to Becker. "Because there is no infrared heat, converters using UV LED technology can run thin and heat-sensitive films without the need for chill rolls. In addition, UV LED systems cure at speeds 20–30% faster using up to 50% less energy and are more compact than traditional UV systems, allowing for more compact printers with shorter web paths that minimize waste and can be used in a wider range of printing environments. Furthermore, the uniformity and long-term consistency of LED lights enable the development of safer, more stable, and more reliable processes for low-migration printing," he adds. Greater safety is an additional benefit; LEDs do not generate UV-C radiation, ozone, excessive heat, or noise. Finally, Becker notes that users report that LED light sources produce better cures and better adhesion on a wide range of substrates, including recycled materials. "They can also achieve higher speeds with black and white inks, and tough opaque whites and dense blacks are much easier to cure," he states. These same economic and operating benefits are being applied to a wide variety of applications such as digital inkjet, display coatings, automotive coatings, wood coatings, electronics adhesives, and medical applications to name just a few.

For wood coating applications, as the cost of LED lamps goes down and their power increases, more fine investments using LED lamps are being made, according to Woods. "They remain the minority at the moment, but we do believe over time the significantly longer bulb life of LEDs coupled with concerns over conventional Hg lamps will increase the usage of LED-cured systems," he comments. Donahue agrees that LED curing is still in the early stages in regards to accommodating the wood coating market. "Wood is a naturally occurring material, and the structural dimensions can vary, resulting in challenges for LED technology," she notes. "For example," Donahue continues, "the lamp-to-substrate distance required for LED curing is very small, making dimensional variances difficult to accommodate. Wood finishers also typically do not coat only flat pieces of wood. They are coating multiple profiles, species, and thicknesses." In metal packaging, LED curing has a great deal of potential if current application speeds can be met in a commercially viable way, according to Lewis.

The performance and power of UV-LED lamps have already increased dramatically since Phoseon first introduced UV-LED lamps to the market in 2004, and that trend will continue, according to Phoseon's vice president Stacy Fender. "Much of this increase is due to the optics, thermal management, and patented technologies we apply at the system level. As LED efficiency increases, air-cooled lamps become more favorable versus water-cooled systems due to overall system savings," he explains. Advanced air-cooled technologies, such as the company's TargetCure™ and WhisperCool™ technology, enable LEDs to perform more efficiently and provide stable UV output over a longer period of time and more power while keeping sound to a minimum. In addition, UV LED lamps are now designed specifically for applications requiring lower irradiance but higher doses, because dose is an important factor when curing coatings and in many cases more important than irradiance, according to Fender.

"There is tremendous excitement for LED curing. If you attend an industry conference, you will be shocked at the number of companies offering LED solutions," asserts Dan Sweetwood, president and CEO of Allied PhotoChemical. He has concerns, though. "In some cases we find that customers are overly optimistic about the capabilities of LEDs. The LED manufacturers are trying very hard to differentiate themselves. I think at times they are overselling the positives and not spending enough time on issues that customers are going to care about over the long term. Customers need to be asking about maintenance, output of the lamp over time, the replacement strategy, etc." As an example, Sweetwood notes that one of the benefits promoted by the LED industry is that LEDs run cooler than microwave or arc lamps. "While this statement is true, the light energy from a powerful LED (more than 8W) transfers a tremendous amount of heat rather quickly. Customers, however, think a cooler running light equals less heat on their substrate, which may or may not be true depending on the line speed. You can burn wood in seconds under a 'cool,' powerful LED," he says.

Even so, Allied PhotoChemical is interested in LED curing. Recently, the company tested a 16W water-cooled unit in its laboratory, and Sweetwood was pleasantly surprised by the amount of energy the unit delivered. The unit operated successfully at cure speeds of greater than 100 feet per minute. "There is no question that LEDs are going to take over a major part of the radiation curing market. It's already happening in the printing world. When it comes to three-dimensional curing, however, there is still a lot of development that needs to take place," he concludes.

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Many Drivers of Development

There are numerous drivers for growth of UV curing in different end-use market. Productivity is often the biggest, according to Joesel. "It all relates back to the speed of reaction. For free-radical polymerization, the rate of reaction is about six orders of magnitude (1,000,000 times) faster than condensation (conventional) reactions. For radiation-cured coatings, the benefits of speed, a small process footprint, and high first-time quality are all dependent on this speed of reaction," he explains. The biggest advantages are realized, however, when UV-curable coatings enable a new technology to move into a new space, according to Joesel. "UV technology was critical to the development of optical fibers, digital recording, and personal and consumer electronics. We expect as new technologies continue to develop, the adoption of UV technology will continue," he asserts.

One overall positive for the United States is the current on-shoring trend, according to Sweetwood. "If you are going to manufacture in the U.S., you need to be efficient. It is ultimately efficiency that drives our market," he states. UV curing also often enables an increase in manufacturing capacity within an existing production environment, according to Woods. The ongoing shift from solventborne systems to formulations with lower VOC content is important as well, according to Krohnen. "Because the formulation of waterborne coatings can be sometimes limited due to external conditions (such as drying conditions, climate, etc.), radiation-cured systems have momentum," he explains.

In the metal packaging industry, the desire to increase the use of radiation curing is largely explained by the vast reduction in applied costs due to production speed efficiencies, the reduced factory footprint, and increased automation for reduced labor intensity, according to Lewis. Energy savings and environmental improvements are further bonuses to change. To continue and maintain growth, however, he adds that there is a need for a larger formulating toolbox of toxicologically proven materials with assigned migration limits based on real data. "This has been hard to gain in the past due to the costs involved, but much of what is needed is now being made available as a result of the EU Registration, Evaluation, and Authorization of Chemicals (REACH) legislation," observes Lewis.

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Challenges can also create opportunities for innovation, and this situation is true for radiation-cured coatings. In the wood coatings industry, many large OEM customers are now focusing on residual photoinitiator content within coatings, which has led to the need for coating formulations that maintain effective performance and cost balances, according to Woods. He also notes that solutions are needed that provide deep color films that can be effectively cured, provide good adhesion, and are over-coatable. The trend toward deep-matte, solvent-free, UV-cured coatings for wood with gloss units below 10 is also challenging formulators, according to Krohnen, because these systems do not experience any film shrinkage, which leads to the need for a high amount of matting agents (e.g., silicas). "Doing so causes a tremendous increase in viscosity, which has a negative impact on application viscosity and makes roller-coater application almost impossible. Raw material suppliers are working to develop customized solutions, including wax additives, wetting and dispersing additives, matte resins, and specific matting agents, to meet these demands," he observes.

For metal packaging applications, most of the biggest challenges relate to gaining proven suitability for food packaging, according to Lewis. "A great deal of the effort from the technical side goes into understanding toxicity and potential migration of components and potential non-intentionally added substances (NIAS), as is the case for many other chemistry platforms for packaging," he comments. He adds that the Swiss ordinance covering inks and coatings for food packaging and the impending German Ink ordinance, which will likely be replaced by proposed EU central legislation, are the most notable from a food packaging safety perspective.

The global food packaging industry also seems to be driving the move away from bisphenol A-based formulations, according to Sweetwood. "This trend makes our job as formulators more difficult, but it can also create opportunities. We are always looking to improve our formulations, even those that have been on the market for many years. The BPA-free requirement forces us to think differently and creatively," he observes.

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Customer specifications in other sectors (e.g., IKEA in the furniture industry) for coating materials that are free of formaldehyde, heavy metals, aromatic solvents, and organotin compounds, like stricter regulations for biocide usage, in fact make radiation-cured system of even greater interest for wood applications, according to Krohnen.
It is also notable to Donahue that on a global level, particularly in China, there is a strong movement toward mandating cleaner technologies. In the United States, on the other hand, she notes that newer EPA regulations implemented under the Trump administration may see greater flexibility. Lewis also believes that legislation restricting the use of mercury lamps, which currently are covered by an exemption, could further drive the adoption of LED curing if LED technology becomes established as a viable proposition for high-speed, wide-format metal decoration.

Equipment Advances

LED technology is rapidly advancing. More power and interesting design variations are now available, such as plug-and-play bulb systems with "on-off" capability and different wavelengths. LED systems also achieve payback in less than three years, meaning that investment in LED cure is becoming a reality for wood coating manufacturers, according to Woods. "The speed of improvements to LED systems is now very exciting," asserts Lewis. "Better cooling, higher power output, and reduction in cost are clear to see," he adds.

Further improvements are still required, however. "We still need shorter wavelength LEDs that are affordable and more powerful," Sweetwood says. He also predicts an eventual "market shake out" in the LED hardware space. "There are a lot of resources devoted to selling LEDs at the moment, but customer service, maintenance, replacement, and down-time avoidance are key things that will always matter. The LED manufacturers that can support the customer after the sale are the ones that are going to be successful long term," he asserts.

While the equipment continues to adapt to high speed, industrial coating line requirements, it remains expensive, and in the wood finishing market the cost/benefit ratio is disproportionate, according to Donahue. "This ratio is currently offset to a degree via the adoption of hybrid processes consisting of combinations of LED and conventional UV-curing systems. The equipment cost and energy consumption benefits close the gap and result in a lower thermal profile to accommodate temperature-sensitive substrates," she explains.

The growing interest in LED curing is driving the development of different photoinitiators and the use of more reactive branched amine oligomers.

For LED-only curing, Donahue also notes that materials need to be formulated to have increased cure responses and/or higher sensitivity to UV exposure to achieve faster cure speeds and better through-cure. "This issue is particularly relevant when curing materials that have structural variations, like wood, which render it impossible for lamps to have a very close proximity to the substrate surface. Thicker applications for both clear and opaque coatings would benefit as well," she says. Formulators also need to be cautious in considering materials where the energy of activation is too sensitive, because package stability may be compromised, according to Donahue. As further advances in raw materials become available, this concept will become more feasible.

For conventional UV-curing applications, AkzoNobel Wood Coatings has partnered with COSTA to bring its "Inert Drying System" to market. With this approach, coatings are cured through a UV-transparent foil that reduces oxygen inhibition, allowing the curing of thicker films and reducing worries about residual photoinitiators. It also provides for a reduction in process steps and delivers an attractive final film quality, according to Woods.

New Chemistries

Raw material suppliers are continually developing new chemistries to address market needs. As is the case in many other segments of the coatings market, the switch from solvent-based to waterborne coatings is a key driver of innovation for radiation-cured systems. The growing interest in LED curing is driving the development of different photoinitiators and the use of more reactive branched amine oligomers, according to Woods. "We have also seen more reactive additives, as opposed to those that are migratory. These chemistries are very beneficial for coatings for food packaging and related industries, as well as for improving coating property longevity (e.g., longer maintenance) of slip properties or mar resistance," Donahue says. Additive suppliers such as BYK are developing tailor-made additive packages, including wetting and dispersing additives, defoamers, and crosslinkable surface additives, as well as specialized matting agents, some of which are inorganic in nature with specific treatments and others that are based on waxes, according to Krohnen.

There is also growing interest in coating ingredients derived from renewable raw materials. AkzoNobel recently introduced several UV coatings that contain renewable raw materials in response to this trend. Most notable, according to Woods, is the company's collaboration with Solvay on the development renewable epichlorohydrin, a precursor to epoxies and epoxy acrylates, and other efforts that have resulted in renewable polyesters.

Regulations are having a two-fold effect, Lewis notes. "At present, many developments are quite conservative/consolidatory due to REACH and the need for global country registrations, which is likely hampering innovation. On the other hand, the movement away from BPA-containing epoxy acrylates has led to interest in more costly urethane chemistries to achieve similar properties, while regulations restricting tin are leading to the development of organic tin-free resins," he observes. ❋