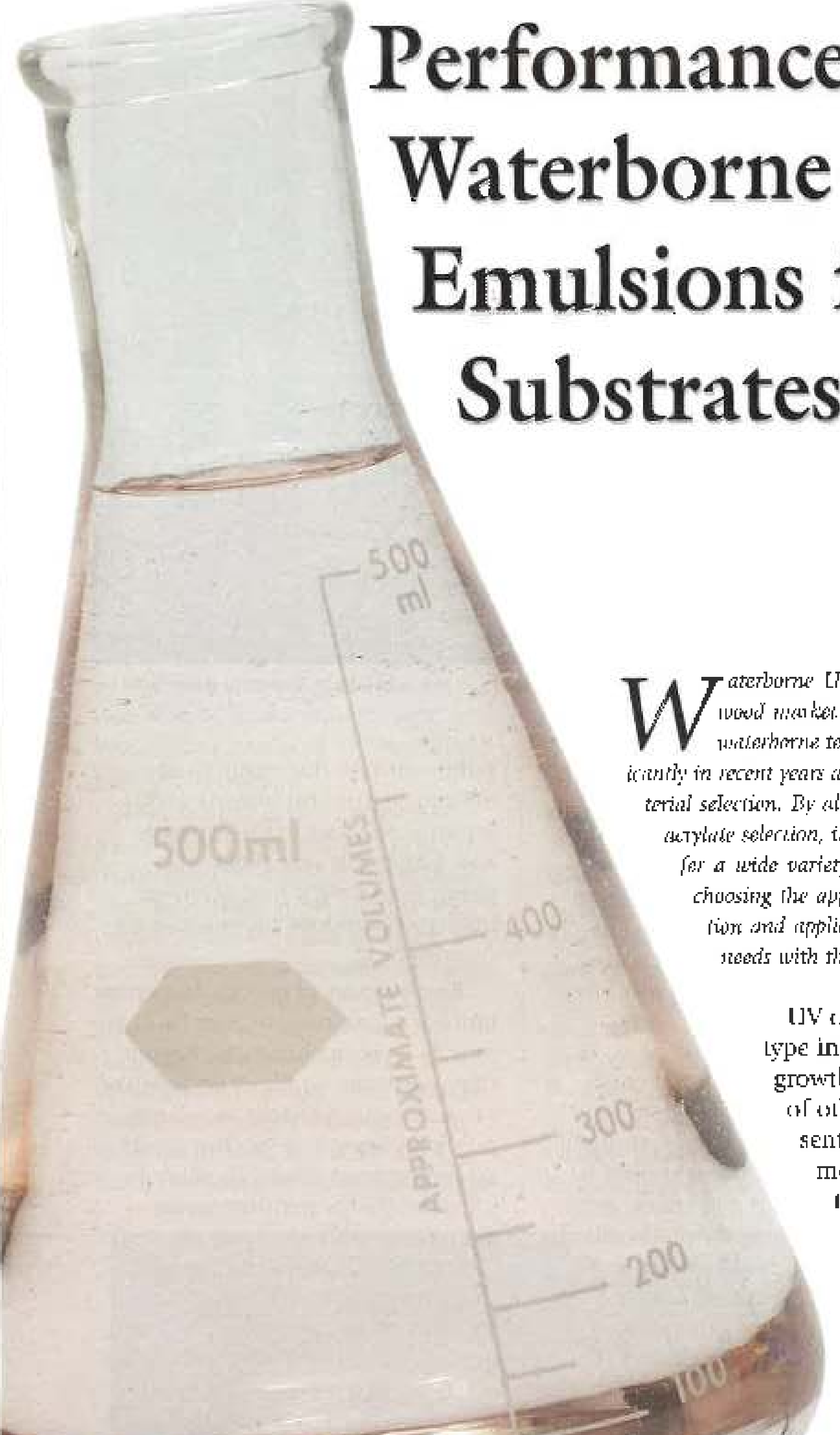

Performance Capability of Waterborne UV-Curable Emulsions for Wood Substrates

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Waterborne UV coatings are slowly gaining share in the factory finished wood market as environmental regulations become more stringent and as waterborne technology improves. The resin technology has advanced significantly in recent years as improvements are made in processing, design, and raw material selection. By altering three basic variables of the waterborne UV resin (UV acrylate selection, incorporation type, and modification), suppliers are able to offer a wide variety of products with tailored performances and behaviors. By choosing the appropriately designed UV resin and managing other formulation and application variables, the coating formulator can meet customers' needs with the use of waterborne UV chemistry.

UV curable technology is the fastest growing coating type in the wood segment with an estimated annual growth rate of 9%, almost three times the growth rate of other technologies.[1] Currently, this chemistry represents less than a tenth of the total wood coatings segment value, and therefore has a large market potential. This wood coatings segment includes such applications as kitchen cabinets, furniture, and flooring. As seen in *Figure* 1, this market segment represents one of the highest percentages of the UV coatings market, and is therefore a desired market for UV coatings and raw material suppliers.[2]

UV chemistry in wood coatings is gaining market share because it enables the end user to increase production efficiency while lowering solvent emissions. It also has the advantage of requiring only a small equipment footprint, so less floor space is needed. The overall system for the coating applicator is cost ef-

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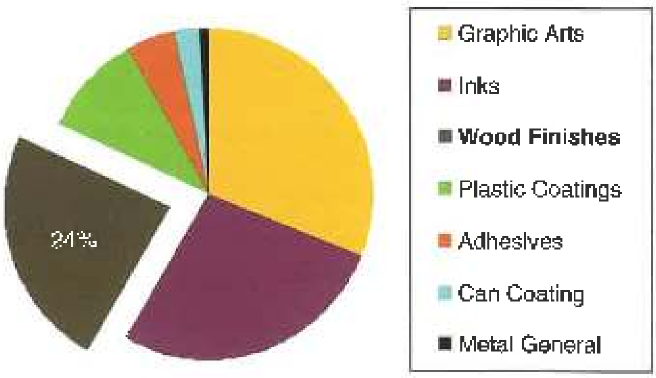
fective because of increased production speeds and lower energy costs. There is also the cost advantage of a quicker inventory turnover of coated parts as UV cure offers the benefits of excellent chemical and block resistance, which allows for stacking, packing, and shipping right off the production line. Although there are many advantages in switching to UV cure, the applicator must overcome several obstacles, including higher equipment costs, higher raw material costs, and the inability to properly cure thick films or complex geometries (see *Table* 1).

In choosing UV coating technology, the formulator has three chemistry options for the UV functional resin: waterborne, 100% solids, and solventborne. The latter two have been the primary technologies available; however, waterborne UV chemistry is becoming a viable and growing alternative due to its advantages (see *Table* 2). Not only does it have the obvious environmental and clean up advantages, but it also can provide low viscosity without the addition of low molecular weight monomers, which can be detrimental to performance. Waterborne UV-curable resins offer excellent adhesion and open pore wood finishing; however, grain raising is possible as with other water-based wood coatings, and is minimized with sanding between coats. Another limitation for the technology is that waterborne UV-curable coatings require a drying oven for the evaporation of water; therefore, a two-step process is needed. This drying step can be in either a forced air infrared oven or a microwave oven, with a typical pre-cure dry time of 5–10 min to evaporate the water, depending on coating thickness.

The chemistry of UV curing is a photochemical process whereby intense ultraviolet radiation is used to crosslink the coating. The process is achieved through a free-radical mechanism which uses a photoinitiator as a catalyst (*Figure* 2). The UV radiation splits the photoinitiator into free radicals which react with the double bonds of the UV resin. This produces more free radicals and the process continues until terminated. With

Figure 1—UV coatings segment breakdown.



the use of multifunctional resins, a three dimensional network can be created and the crosslink density can be controlled to meet the needs of a variety of coatings applications. The chemistry of waterborne UV curing follows this reaction process, with water being present as the diluent. Because water is very efficient in viscosity control, the UV resin can have high MW and functionality, therefore leading to higher coating performance.

The development of waterborne UV resin technology has advanced significantly in recent years, with the growing ability to tailor the resin for specific performance needs.[7] There are three basic variables used in the industry to influence the final properties of the resin: UV acrylate selection, incorporation type, and modification.[2, 4] Because there are a multitude of combinations and choices resulting from these variables, there are a wide variety of waterborne UV products available with different performance and behavior.

There is a large selection of UV acrylates available with varying backbones and functionalities. The choice and amount of this UV functional material used in the final product impacts the final crosslink density of the

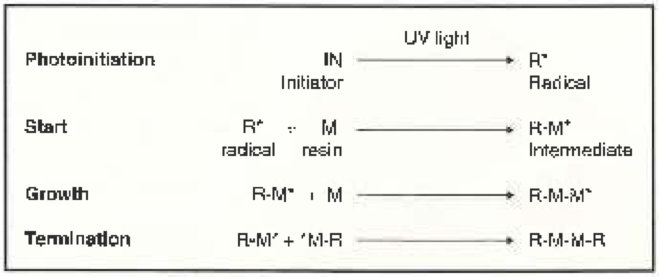
Table 1—UV Coating Advantages

Benefits	Limitations
Low solvent emissions	High equipment costs
High-end coating performance	High material costs
Smooth finish	Difficult to cure thick coatings
Rapid production	Difficult to cure complex geometries
Less floor space	Some types have skin/eye irritations
Extended open time during use (recyclable)	
Low cost per finished sq/ft	

Table 2—Waterborne UV Advantages

Benefits	Limitations
Low viscosity without reactive diluents	Grain raising
Zero-VOC capable	Drying ovens required
Low build appearance	Humidity dependence
Water clean up	Finish defects (incomplete dry)
High hardness and flexibility	Must keep wet coating from freezing
Excellent adhesion	
Resoluble/reclaim	
Easier equipment retrofit	
Gloss and viscosity control	

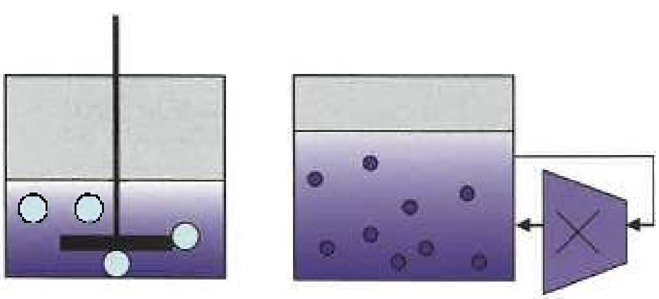
Figure 2—UV polymerization reaction.



coating. The differentiation between UV acrylates is not only the amount of double bond functionality, but also the product family type such as acrylic, urethane, epoxy, or polyester acrylates. It is now becoming more common to use these algometric or polymeric compounds to add the double bond functionality rather than the monomeric acrylates.[5]

The processing and incorporation of the UV acrylate determines the overall polymeric structure of the final product, therefore contributing to the macro properties of the coating. Examples of this incorporation include external emulsification or a self-emulsifiable dispersion (*Figure* 3). External emulsification is simply the process of distributing the acrylate into water with emulsifier and high shear forces. Products of this nature are often referred to as an emulsion, a solution, or water dilutable. The emulsification process of such products is very sensitive, which can cause stability issues during the processing as well as in the formulated coating. However, the product type offers the advantage of high-solids and an easier and direct conversion of current solvent-based UV systems to waterborne UV using the same base chemistry. Although this incorporation type seems rather straightforward and undeveloping, there are continuing advances and uses of such type.[3] The second incorporation example is a dispersion, which utilizes polyurethane chemistry to create a UV functional PUD (polyurethane dispersion). These UV PUDs can be polyether, polyester, and/or polycarbonate based

Figure 3—External emulsification versus self-emulsifying dispersion.



and are often referred to as dispersions, UV-curable PUDs, or acrylated PUDs. These products offer the typical advantages of polyurethanes such as flexibility and toughness, and show the highest growth rate in waterborne UV technology due to their unique performance. Within this PUD incorporation type, there are multiple design and processing parameters that are also available for final resin design such as the isocyanate type or the polyfunctional building block.

The third variable, modification of the product, is a key differentiator between products that fine tunes the behavior and performance of the final coating. The modification can be interim or post process, include multiple incorporation methods, and involve other chemistries. These modifications are not typically defined by the supplier and are the key to their product differentiation. Common industry examples of such modifications include the post addition of an acrylic emulsion for exterior stability, the modification with dispersants for shelf stability, or the addition of an externally emulsified acrylate for adjustment of drying properties.[3,4]

Given all of these variables, it is possible to design the waterborne UV resin to meet many coating performance needs. *Figures* 4–7 demonstrate how the various incorporation methods and modifications can impact coating performance. *Figure* 4 is an example of the effect of UV variables on coating stability as measured by a 30-day hot box viscosity. Waterborne UV PUDs (Samples A and B) typically have stability issues due to the UV acrylates' impact on the dispersion dynamics. By various modes of modification, this stability issue can be resolved. Unfortunately, this modification can be a detriment to the very good wood warmth of a pure PUD (*Figure* 5) and can reduce the level of tack, or hardness, prior to cure (*Figure* 6). External emulsifications have a moderate level of performance across all measurements and, therefore, are rarely seen without modification.

Level of tack prior to UV cure is a very important performance criteria for UV coating customers and is typically defined for each UV resin. Some customers prefer the coating to develop significant hardness before UV cure, while others prefer the coating to remain tacky. A hard coating surface can protect parts from dust contamination before entering the UV chamber

Table 3—UV Bulb Selection Guide

Bulb Type	Wavelength (nm)	Uses
H	240–320	Clearcoats
D	350–400	TiO_2
V	400–450	UV absorbers or nanoparticles
Q	430–470	Pigmented coatings or specialty

and can also allow a level of property development even if some areas of the part do not receive sufficient UV light. A soft or tacky surface allows better flow into the wood pores before UV cure and can help the overspray to be re-emulsified and reused. As seen in *Figure* 6, the level of tack can be dialed in by modification.

Because different types of waterborne UV resins can provide different performance parameters, resin suppliers and coatings formulators can choose to combine different technologies to optimize the properties needed. *Figure* 7 is an example of a mixture design output for the determination of an optimal blend ratio. In this example, three components were combined with performance measurements in clarity, flexibility, and hardness before and after cure. The optimal ratio is highlighted in the yellow area.

Another design option for waterborne UV resins is the incorporation of functional groups with dual cure potential, which further enhances the coating performance level. With these resins, it is possible to not only crosslink by radical polymerization with UV light, but also by polar group reaction of the resin with an isocyanate. The advantages of a dual cure system are increased hardness, adhesion, scratch resistance, and chemical resistance. Dual cure is especially recommended for three-dimensional applications in which some of the segments are not exposed to UV light.

Waterborne UV resins, especially PUDs, are typically not zero VOC due to low solvent levels coming from the processing and raw materials. For traditional PUD manufacturing, NMP solvent is used for viscosity control and is present in the final product up to 10%. However, there have been recent developments of "solvent-free" PUDs which are manufactured without NMP solvent. With these new PUDs, it is now possible to formulate coatings that have nearly zero VOC emissions. As seen in *Figure* 8, these new solvent-free PUDs have minimal detriment on performance.

Not only is the waterborne UV coating impacted by the type of resin used, but it also is affected by the other formulation ingredients: surfactants, defoamers, waxes, matting agents, pigments, photoinitiators, and thickeners. These ingredients have the typical interactions and influences as in traditional coatings. However, the photoinitiator is one of the key primary components for a UV coating and should be chosen carefully. With the increased popularity of waterborne UV coatings, photoinitiator manufacturers are now producing many water-stable versions of their standard products.

The choice of photoinitiators is determined by several factors: coating type, light source, and additive package. The first consideration is whether the coating is clear or pigmented because of the interaction of the

Figure 4—Waterborne UV variable effect on stability.

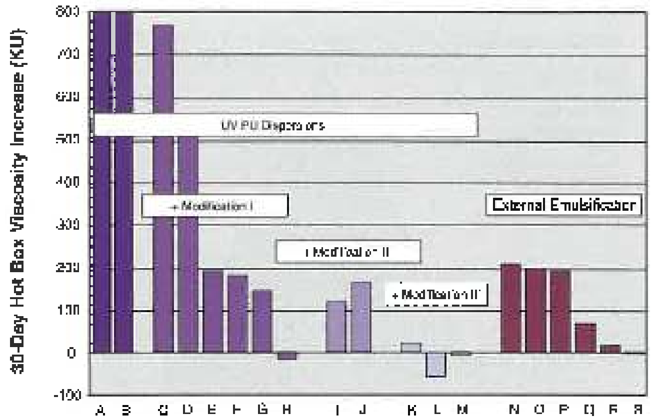


Figure 5—Waterborne UV variable effect on wood warmth.

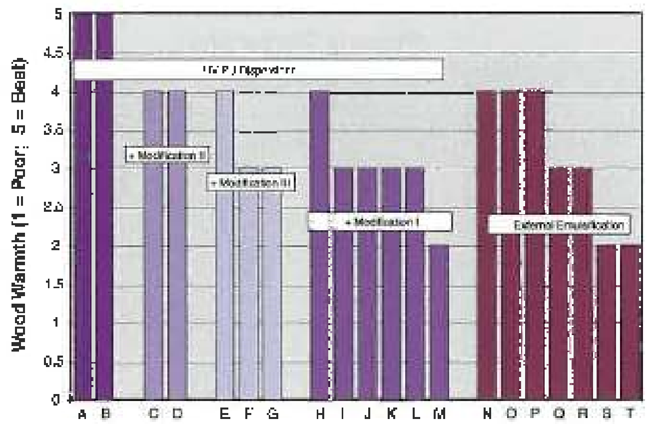


Figure 6—Waterborne UV variable effect on tack.

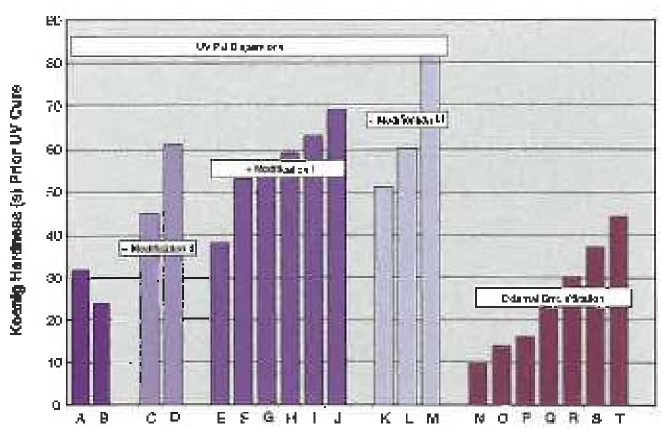


Figure 7—Optimizing a waterborne UV system.

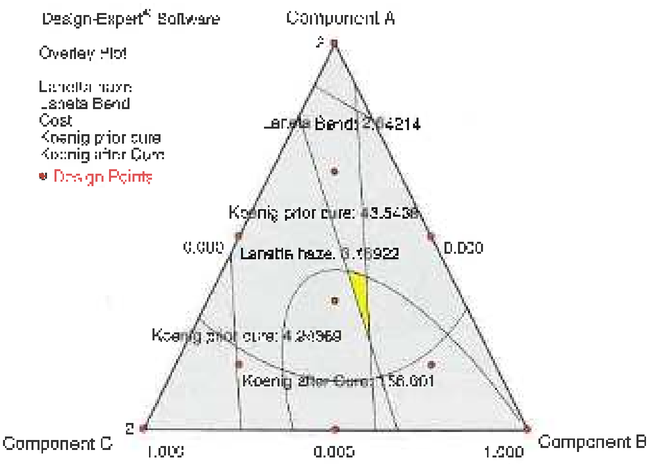
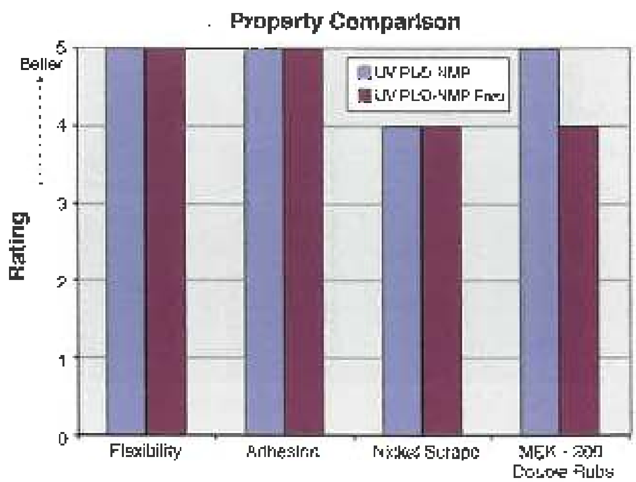


Figure 8—Comparison of solvent-free PUD coating performance.

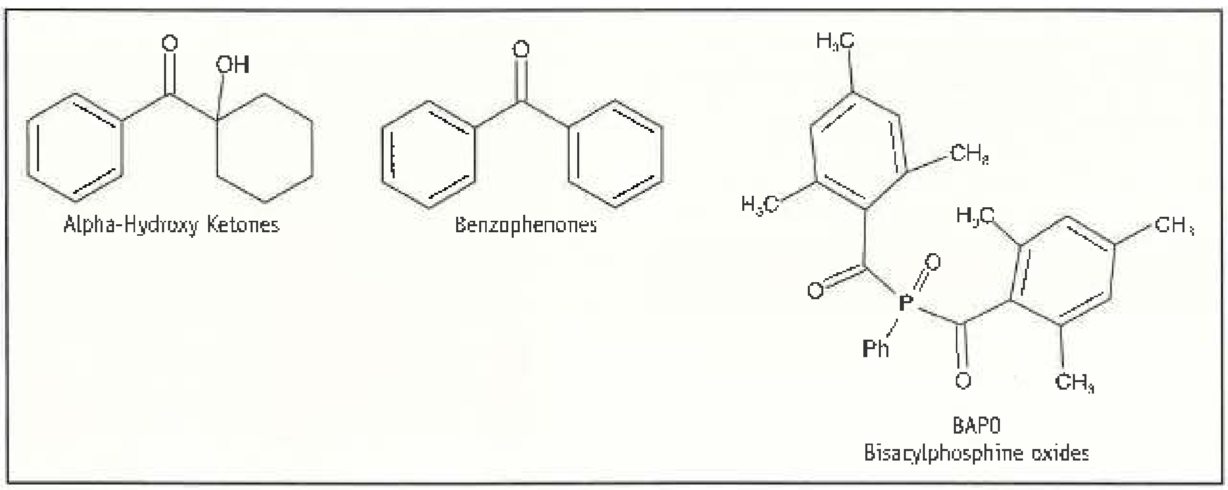


photoinitiator with the pigments. For clears, an alpha-hydroxy ketone or benzophenone photoinitiator is recommended. For pigmented coatings, bis-acyl phosphine oxide in addition to the α-hydroxy ketone or benzophenone should be used. Chemical structures of these key photoinitiator types are shown in *Figure* 9. The absorbance of the photoinitiator should be matched with the spectral output of the light source for maximum cure potential. Care must be taken when formulating with photoinitiators, as there is a large impact determined not only by the type chosen but also the level. Adding too much photoinitiator can hinder cure because the excess will act as a UV absorber and prevent the UV light from penetrating into the coating. Therefore, it is recommended that the optimal level be determined by experimentation.

The amount of UV exposure impacts the degree of cure for the coating, and therefore has a major impact on the performance capabilities. This amount of exposure can be impacted by several factors of the UV line: irradiance, spectral distribution or wavelength, line speed, and surface temperature. For most UV-curable materials, energy alone is not an adequate measure of the level of exposure; therefore, all factors must be specified for consistent cure and performance. For example, a low irradiance exposure for a long time period does not yield the same result as a high irradiance exposure for a short time period.

Another impact on the degree of cure comes from the bulb choice, which is the same despite the UV chemistry type used. Bulbs with shorter wavelengths, type H, are used for clears and surface cure of pigmented coatings. Bulbs with longer wavelengths, type D, V, and Q, are used for through cure of pigmented coatings and with certain additives such as UV absorbers and nanoparticles. When multiple light sources

Figure 9—Key photoinitiator types.



are needed, the bulb with the longest wavelength should be used first to ensure the coating gets its through cure before its surface cure. Otherwise, micro-wrinkling and other film defects can occur.

CONCLUSIONS

Waterborne UV coating technology is continuing to improve and therefore gain market share as raw material suppliers and coatings manufacturers better understand the technology and designing of equipment. As they become more robust and higher performing, the waterborne UV systems will continue to replace other chemistries due to production efficiency and low VOC emissions. This is very evident in the high volume cabinet, door, and paneling markets where waterborne UV coatings are growing to become the standard technology mainly due to their low build appearance and their enhanced performance in wood warmth and chemical resistance. With improved processing, modification, and raw material selection, more waterborne UV resins are being introduced to the market and can meet the needs of customers requiring alternative technologies. As the wood market becomes more comfortable with waterborne UV technology, product development will continue to penetrate into new areas such as exterior applications and nontraditional substrates. CT

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