CASE STUDY

High-Quality Performance, UV-Curable Industrial Finishes for Wood

By Lawrence (Larry) C. Van Iseghem

As a manufacturer of performance UV-curable coatings, we have successfully formulated coatings for virtually all types of substrates and application methods. When developing UV-curable and waterborne coatings, we employ specific methods that we refer to as "Application Specific Advanced Coatings™" (ASAC) technology. Of the countless projects we have undertaken, the greatest challenges and resulting accomplishments seem to be associated with wood finishing.

This article reviews a sizable project that involved a number of factors which had to be integrated in the finishing of interior woodwork. The final result, after intensive efforts, is a UV-curable finish system that evolved to deliver unrivaled performance, quality and value.

The fact that wood is so challenging may not be immediately apparent. It is true that anyone can effectively finish wood, but few can actually do it well to professional standards. Typically, we are called upon to support wood finishers that require "excellence." This requires serious attention to detail and a considerable effort by our technical team assigned to the challenge. Consider:

- **No two pieces of wood are alike.** Even within a specific log of a specific species there are structural differences. Open grain, closed grain, heart cut, early growth, late growth, sap and pitch content, tannins, oils, retained moisture content or absence, and more may all influence the quality of a finish or treatment to the wood surface. The coatings formulator needs to consider natural wood variation in development activities to achieve the targeted finish of excellence. Therefore, wood properties represent a considerable challenge to the formulator but, importantly, they represent only a part of the total challenge.
- **The finishing process is a system of many moving parts.** The formulator is required to consider a number of variables, including the tools, equipment and methods of the process environment that can influence the quality of the final finish.
- **No two finishers or operators are alike.** People will have individual opinions, visions or thoughts of how best to set up the application process. The coatings formulator must, therefore, manage a number of variables and develop a finish system that allows for an acceptable window of operating latitude and still conform to performance specifications.

Finishing wood, therefore, is not trivial when targeting excellence. The coatings formulator is responsible for the integration of a number of important factors that influence finish quality—namely people, process and chemistry.

This article reviews a sizable project that involved a number of factors which had to be integrated in the finishing of interior woodwork. The final result, after intensive efforts, is a UV-curable finish system that evolved to deliver unrivaled performance, quality and value.

Case Study Criteria

The UV-curable finish system was required to conform to the following criteria:

- **Substrate**—multiple species, including basswood, poplar, oak and cherry
- **Wood Dimensional Types**
  a. Lineal profiles
  b. Flat panels
- **Application Thickness**
  a. Paints—2.00 mil ± 0.25 mil
  b. Clears and Stained—1.00 mil ± 0.25 mil
- **Colors**
  a. Paints—10 shades from white to beige with full opacity/hide
  b. Clears and stained—32 colors from natural to black
- **Color Tolerance**
  a. Paints—color spectrophotometer measurement vs. color control
    i. Initial ≤ 0.5 ΔE (CIE L* a* b*)
    ii. 1,500 hr. Xenon arc: ≤ 1.0 ΔE
  b. Clears and Stained—visual conformance to color control
    i. The color inspector must obtain a score, using the Farnsworth-Munsell 100 Hue Test, between 0 and 16.
    ii. 1,500-hour Xenon arc—minimal discernable change
- **Other Finish Performance Criteria**
  a. Water/moisture resistant
  b. Chemical resistant to solvents, cleaners and contaminants
  c. Nickel mar-resistant painted surface
  d. Scratch and abrasion resistant
  e. No finish flaking upon saw cuts and hole drilling
  f. Impact resistant
  g. Must pass "X" scribe tape pull adhesion testing

Where to Begin

As the performance criteria list indicates, the finish system needs to address tight tolerances and remain stable over extended periods of time. Of significance, when we were approached to undertake this project, the wood products manufacturer had no prior experience in finishing. In fact, only a few of the employees were familiar with finishing operations from past experiences with other employment. Therefore, significant training and instruction was required in UV technology and finishing methods. To the wood products manufacturer (our customer), this represented a very large investment and the potential risk was high. The successful completion of this project ultimately enabled them to compete with the cost of imported materials and allowed them to offer product of unsurpassed quality.

In retrospect, one of the most important responsibilities we had was to effectively communicate **that the installation of a UV finishing line does not represent a "plug-and-play" or "turn the switch on and run" scenario.** There were a number of obstacles to overcome, but, through excellent teamwork, we ultimately achieved success. Today, our customer is capable, efficient and cost-effective in delivering quality product.

The project began with a series of meetings detailing the type of products to be finished, finish performance criteria or specifications, volume of each to be finished, cost targets and need for the process to be low in volatile organic compounds (VOCs) and zero in hazardous air pollutants (HAPs). It was agreed that the finishing process needed to consist of:

1. Application Process
  a. Lineal profiles—vacuum coating, full circumference
  b. Flat Panels—roll coating, both sides and edges

2. UV-Curable Finish Chemistry—Allows Conformance To:
  a. Process speed, productivity and efficiency to produce:
    i. Profiles—20,000 lineal ft./day
    ii. Panels—80,000 sq.ft./day
  b. Cost
  c. High transfer efficiency
  d. Ultra low VOCs and zero HAPs

3. Wood Species
  a. Basswood
  b. Poplar
  c. Oak
  d. Cherry

Application Process

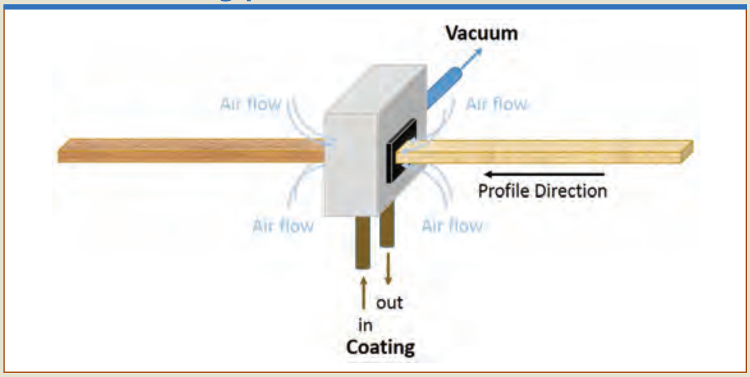
Vacuum Coating of Lineal Profiles

Vacuum coating was selected as the best method for finishing lineal profiles and a system was installed, including a UV-curing oven (multiple UV lamp curing chamber). The process of vacuum coating allows uniform coverage around the circumference of lineal profiles and the use of UV curing allows for speed and efficiency.

A vacuum coater essentially consists of a rectangular box with a lineal profile entry and exit hole cut (in the shape of the profile) on opposite sides. A vacuum pump is connected to the box to pull a considerable volume of air through the gap existing between the profile and the holes cut into the box. The air volume drawn into the gap effectively meters (or doctors) off excess fluid, leaving a wet coating film layer on the profile as it exits the

Figure 1

Vacuum coating process



coating head. The thickness of wet film is dependent on the speed of the profile and the vacuum pressure applied. Typically, the profile hole is cut in a panel positioned over a standard cutout in opposite sides of the vacuum box. The panel is commonly referred to as a “template” and each lineal profile shape will require a separate template. Carefully positioning the template will provide a uniform gap around the profile circumference for optimum finish quality. See Figure 1.

Vacuum coating application head

The profile is entering the vacuum head or box through the black template. See photo above. Note that the vacuum coating head is in position just before the entrance to the UV-cure lamp section or oven. Although the vacuum coating process is remarkably versatile to apply 100% UV-curable coatings, the actual process varied depending on the type of finish desired. The schematics shown in Figure 2 illustrate the processes for clear, stained and paint finishing.

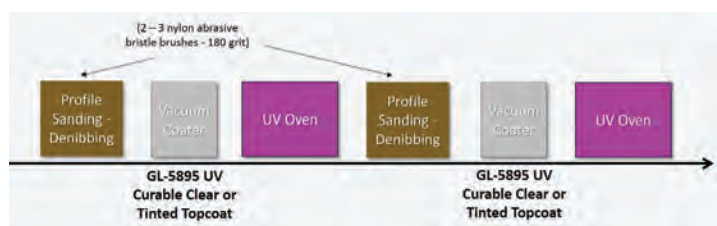
100% UV-Curable Clear Finishing

100% UV-curable clear finishing is a relatively simple process using an initial profile sanding station equipped with nylon abrasive bristle brushes or alternatively brush sanding rolls can be used. The use of either 180 grit or 220 grit media is usually adequate. The profile then enters the vacuum coating head followed immediately by the UV curing oven, another profile sanding station, a second vacuum coating head and then the final UV oven. See Figure 2A.

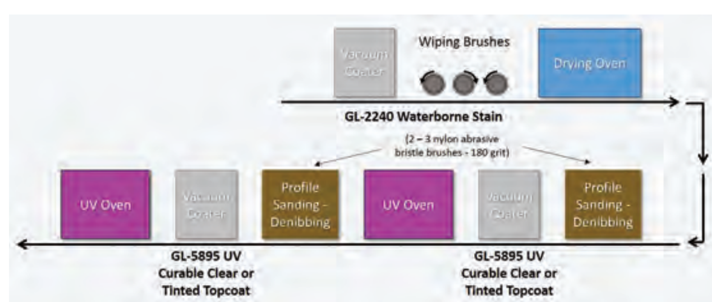
Figure 2

Processes for clear, stained and paint finishing

A. UV-curable clear finish vacuum coat process



B. UV-curable stained finish vacuum coat process



C. UV-curable painted finish vacuum coat process

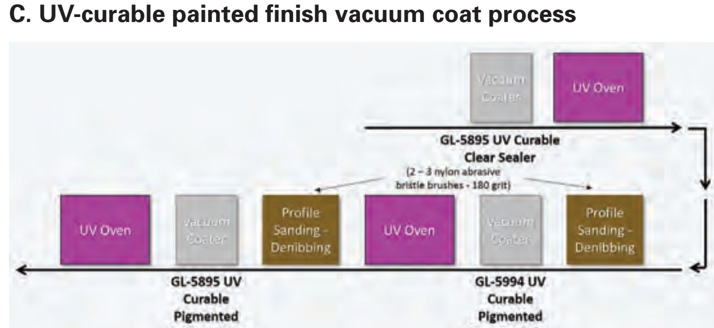
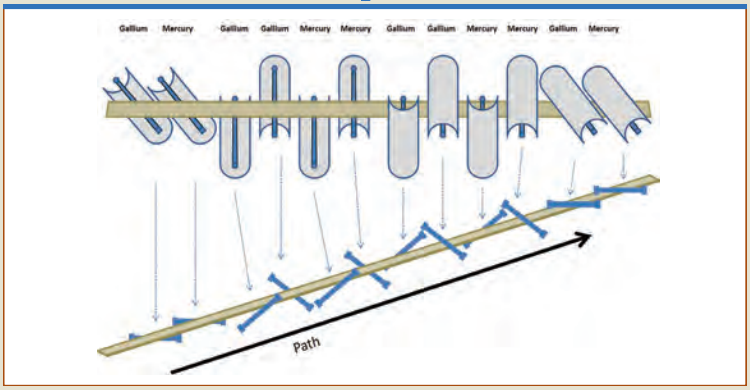


Figure 3

Initial UV cure oven configuration



Waterborne Stain and 100% UV-Curable Clear or Tinted Clear Topcoat Finishing

The stained finish process is very similar to the clear finish process described earlier, but includes another vacuum coating head for waterborne stain application followed by an IR oven for drying the stain prior to mild profile sanding/denibbing and clearcoat application. See Figure 2B.

100% UV-Curable Painted Finishing

Painted finishing is achieved on a second vacuum coat line to avoid the difficult cleanup that occurs when making the transition to clear coatings from pigmented coatings. The first application in the paint process is to apply a clear sealer due to its relative ease in curing versus pigmented coatings. This clear layer provides an excellent anchor for the subsequent pigmented layer. The remainder of the process proceeds similarly to the other processes with the exception of the use of a combination of gallium-doped mercury and mercury-vapor lamps. See Figure 2C.

The UV lamp sections or ovens for the vacuum coating lines have a configuration capable of delivering sufficient UV energy density for both clear and heavily pigmented coatings. There are a significant number of lamps positioned to effectively cure the full circumference of the profile at line speeds sufficient to process the daily quota of material. The UV oven is comprised of a combination of 300 wpi gallium-doped mercury vapor arc lamps (gallium lamps) and standard 300 wpi mercury-vapor arc lamps (mercury lamps) to accommodate the clear and pigmented 100% UV-curable coatings that were developed for this process. See Figure 3.

Roll Coating of Flat Panels

Roll coating was the method selected for the finishing of flat panels. The surface area to be finished per day required a single pass process to keep labor and process time to a minimum. The roll coaters installed were capable of widths up to 48” and they provide sufficient capacity when running between 30 fpm and 40 fpm. Two lines were installed—one for clear and stained finishes, and one for paint finishes—with each having multiple heads for sufficient surface finish build at high surface smoothness.

Figure 4 depicts the application of a UV-curable coating onto a wood panel. The wet thickness of the applied coating is dependent on the gap between the doctor roll and the applicator roll, and the speed of the doctor roll rotation in relationship to the speed of the applicator roll rotation. The best control of surface coating quality and low applied wet film thickness was achieved by running the doctor roll in reverse rotation in relationship to the applicator roll when considering the gap between the two rolls. This process delivers high surface smoothness and uniformity when using UV-curable coatings of the optimum fluid flow properties (viscosity, surface tension, thixotropy, density, etc.).

For greater clarity, the schematics in Figure 5 illustrate the difference between reverse doctor roll and forward doctor roll processes.

Figure 4

Roll coating process

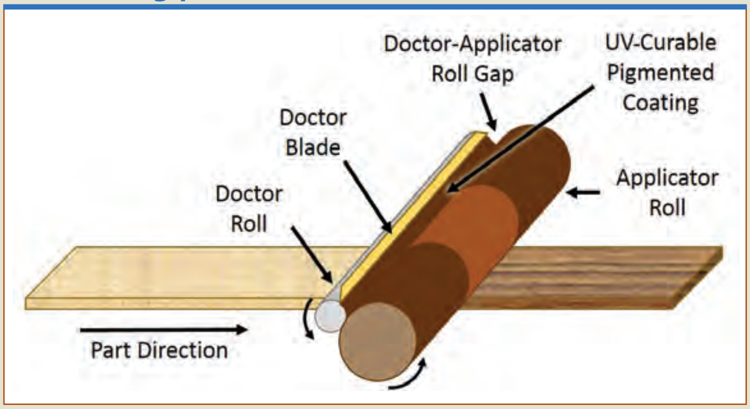
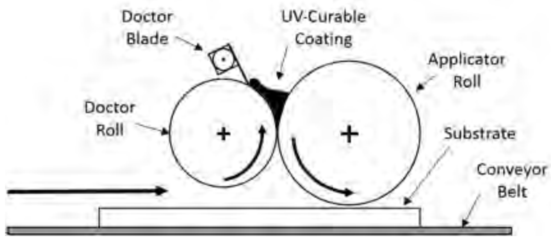


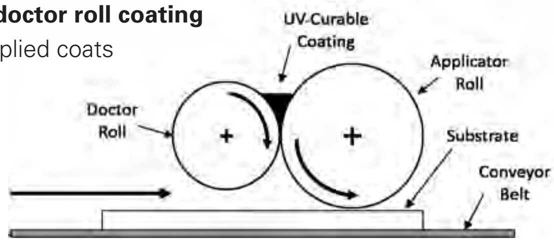
Figure 5

Reverse and forward doctor roll coating processes

Reverse doctor roll coating
Smoother, thinner applied coats

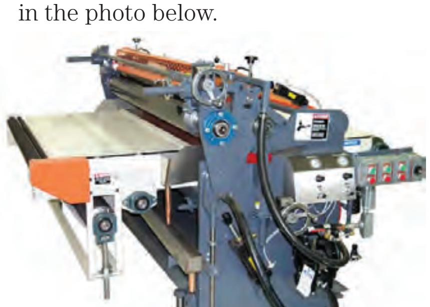


Forward doctor roll coating
Thicker applied coats



Notice that the reverse doctor roll process requires a doctor blade to prevent coating transport around the circumference of the doctor roll.

The actual direct roll coater of the type used in this project is shown in the photo below.



(Courtesy of Dubois Machine Co., Jasper, Ind.)

100% UV-Curable Clear and Stained Finishing

The 100% UV-curable clear and stain finish line contained four roll coating heads. The initial roll coating head is equipped with a sponge applicator roll specifically designed to apply waterborne stains. The doctor roll in this station is run in forward rotation and does not require a doctor blade. Application thickness is controlled by the gap pressure between the doctor roll and sponge applicator roll. The stain application is followed by three wiping brushes and an IR oven to dry the applied waterborne stain. The remaining three roll coating heads are used to apply either a 100% UV-curable clear or tinted self-sealing topcoat. Each UV-curable coating application is followed by a UV-curing oven and nylon abrasive bristle brush abrading sections are also positioned after the first two UV-curing ovens for sufficient intercoat abrading.

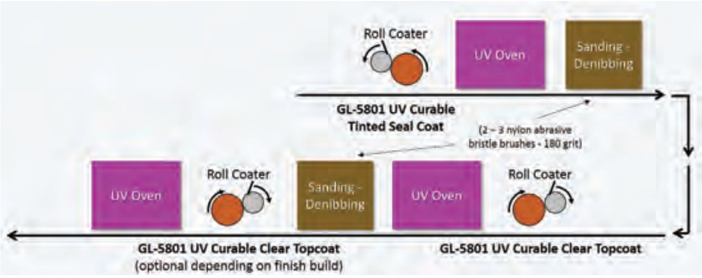
The schematics in Figures 6 and 7 illustrates the clear and stain finish methods along with close-up pictures of the applicator-doctor roll gap as a clearcoat and tinted topcoat are applied.

100% UV-Curable Painted Finishing

The 100% UV-curable paint finish line is separate from the clear and stain finish line and also contains multiple roll coating heads to enable full coverage and opacity of the finish in a single pass. See Figure 8. The configuration is similar to that of the clear and stain finish line with a major difference occurring between the second and third roll coating heads. These two

Figure 6

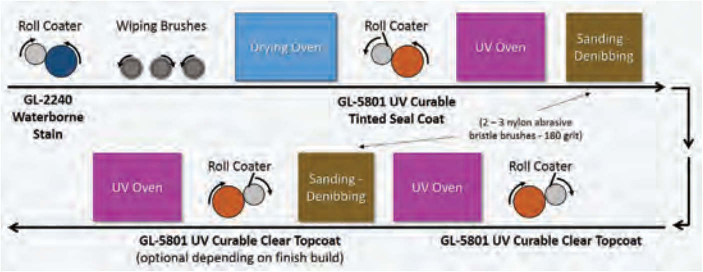
UV-curable clear finish roll coat process



Close-up of clear UV-curable coating in the gap between the doctor roll and applicator roll of a direct roll coater.

Figure 7

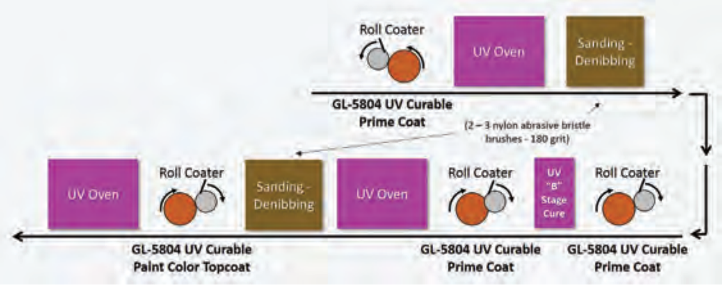
UV-curable stained finish roll coat process



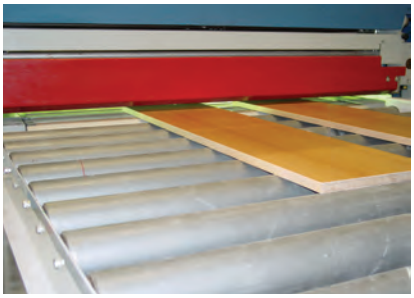
Close-up of tinted UV-curable coating in the gap between the doctor roll and applicator roll of a direct roll coater.

Figure 8

UV-curable painted finish roll coat process



heads were originally designed as a wet-on-wet application station, but is currently modified by a UV-cure lamp between each coating head. This UV-cure lamp provides partial cure of the applied UV-curable paint (a method commonly referred to as a "B" staging or "bump" curing). The "B" staging promotes intercoat adhesion without the requirement of intercoat abrading. Note that it is common to observe that there is difficulty in achieving adhesion between fully cured UV compositions



Panels exiting a three-lamp, UV-curing oven on a clear and stained finishing line

unless the underlying layer is sufficiently abraded to offer surface texture for mechanical bonding. "B" stage curing allows residual chemical functionality to exist in the underlying, partially cured layer such that it will react and bond with the topcoat layer as it is fully UV cured. This permits tight, permanent intercoat adhesion.

In all instances (except when "B" stage curing), the UV ovens that follow the UV-curable roll coaters contain three lamps. The "B" staging step, after the second roll coater on the paint line, contains a single mercury lamp. The three-lamp UV ovens of the paint finishing line were all comprised of an initial gallium-doped mercury vapor lamp followed by two mercury vapor lamps. The clear and stained finishing line contained only mercury vapor lamps.

Edge Coating Flat Panels

To complete the finishing of the flat panels, edges were finished using

Figure 9

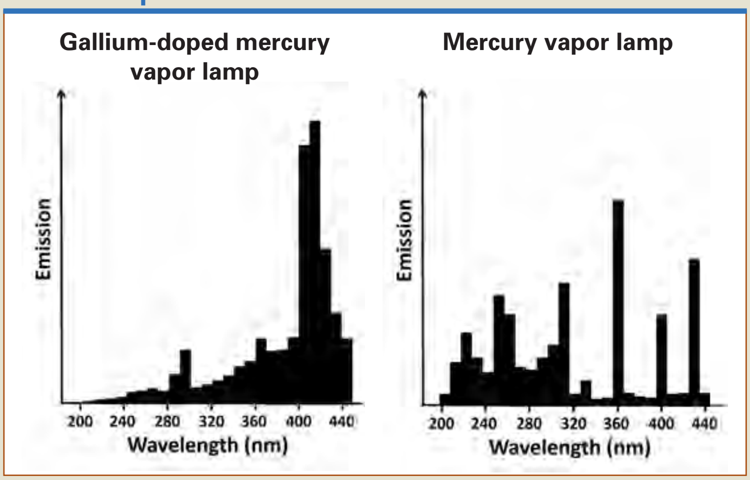
Edge coating

Edge coating panel using clear UV coating

Edge coating panel using pigmented UV coating

Figure 10

Relative spectral emissions



UV-curable coatings that were applied using an edge roll coater. The operation is very similar to the flat surfaces, but with the applicator head positioned vertically. A reverse doctor rotation was also used with a doctor blade preventing continuous wetting of the circumference of the doctor roll. The fluid was injected into the gap between the applicator roll and doctor roll via a slotted tube. Figure 9 shows the actual process application.

UV-Curable Coatings and Cure Process Development

The use of UV-curable coatings (as supported by waterborne stains, when necessary) was considered at the onset of the project to be uniquely capable of providing the desired combination of speed, efficiency, cost-effectiveness and "green" characteristics needed by the finisher. A considerable R&D effort, however, was required to deliver the specified performance and resulted in the following types of coatings for both vacuum coat and roll coat application:

- Waterborne stains
- UV-curable self-sealing topcoats (clear and tinted clear versions for depth of color)
- UV-curable primer
- UV-curable paints

The development project proceeded smoothly and predictably for the formulation of 100% UV-curable clear coatings. The development of 100% UV-curable tinted topcoats and paints, however, required more creative and intensive R&D. For example, we needed to consider:

- The degree and type of pigmentation needed, and
- The need for two formulations for each tinted topcoat and paint color to support
  a. Vacuum coating
  b. Roll coating

It is well-known that pigmentation for color and opacity can interfere with UV light transmission, making it difficult to achieve complete through-cure of the applied coating. Insufficient cure often leaves a weak coating substrate interface, resulting in poor adhesion. With proper formulation, using the proper grades of pigments, types of colorants and the use of the right balance of photoinitiators, the ability to cure the applied coating is made more favorable. Additionally, the use of gallium lamps in combination with mercury lamps can promote the full cure of heavily pigmented UV paints and tinted topcoats. Figure 10 illustrates the relative spectral emissions from gallium and mercury lamps.

The primary advantage of a gallium lamp is its effectiveness to cure UV-curable paints where the predominant pigment is white titanium dioxide (TiO_2). TiO_2 possesses strong UV absorption properties below

Figure 11

TiO_2 overlay on UV lamp output

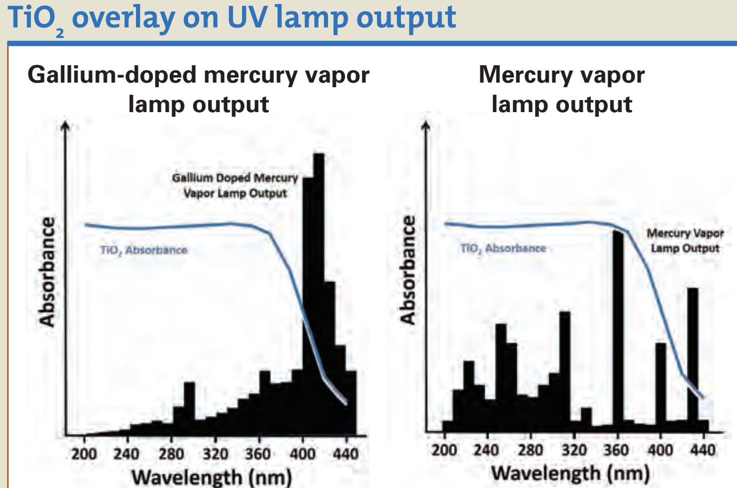
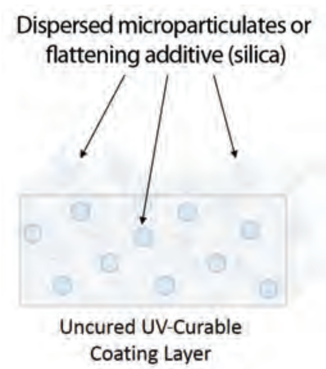


Figure 12

Dispersed microparticulates or flatting additive (silica) suspended in the applied UV-curable coating layer



400 nm and will inhibit cure, especially when using mercury lamps. The same spectral emission figures are shown again in Figure 11 with the addition of an overlying absorbance spectra for TiO^2. Notice that gallium lamps emit a considerable amount of energy above 400 nm. This emission range coincides where TiO_2 exhibits lower absorption and with the selection of the appropriate photoinitiators, effective cure is possible even with considerably high levels of TiO_2.

Additionally, gallium lamps are recognized for their ability to promote through-cure, whereas mercury lamps cure predominantly from the surface down through the depth of the applied coating. The use of a combination of gallium and mercury lamps will promote cure throughout the entire thickness of the applied UV-curable coating.

With the right equipment in place, formulations were developed for all colors to support both relatively low-viscosity vacuum coating and high-viscosity roll coating. As indicated, there were 10 paint colors and 32 clear and stained colors that need to be applied in the overall program. Considering the two methods (vacuum and roll coat), the total number of coatings to be formulated was double the number of colors and all needed to be applied and cured using the single-pass processes detailed earlier. Of course, as with most finishing facilities, there are occasions where additional colors are needed on a custom basis and times where other adjustments are necessary. Therefore, standardized clear and pigmented bases were also provided to allow for these occasions.

We next began the integration of process and the developed chemistry. Process variables were fully evaluated and managed to accommodate the full range of finish colors to be achieved on all target wood species.

It was observed that the lighter shades of tinted topcoats and paints processed with relative ease, but darker colors presented greater sensitivity to the heat-of-cure reaction and the IR energy emitted from the UV-cure lamps. Specifically, the darker the color (using the same base chemistry and process conditions), the lower the relative surface finish gloss values. We considered two options to compensate for this surface-gloss variance with color. The first was to adjust the base chemistry to result in higher sheen values and the second was to adjust the cure conditions to induce higher sheen values. The latter was chosen to avoid the inventory of additional base compositions and to eliminate the chance of the wrong base being used when custom color matching darker colors. We found that, in this situation, the most effective means of gloss control was to manipulate the sequence of gallium and mercury lamps used in the final curing oven.

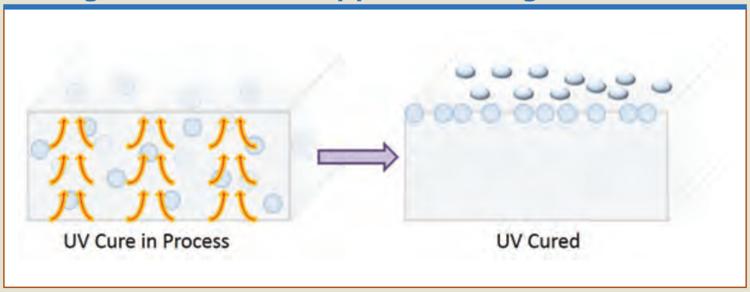
In general, the higher wavelength emission of a gallium lamp promotes depth-of-cure relative to a mercury lamp and, in most process situations, it is positioned as the first lamp in the UV oven configuration. We observed, however, that the darker paint colors formulated were exhibiting too low of a surface gloss value. By repositioning the mercury lamp to be first in sequence, the topmost surface of the applied coating was effectively closed a moment earlier. The migration of the flatting additive to the surface of the applied coating was, thereby, inhibited, resulting in the elevation of gloss to the desired level. The sequence of lamps provided for simple and effective control of surface gloss for all colors applied without the need for reformulation and the need for added coatings to be inventoried.

Surface finish gloss is a property we manage well in our UV-curable coatings and involves factors associated with both chemistry and process.

The surface gloss of a 100% UV-curable coating is generally a property associated with the ability of a microparticulate to be preferentially located at or near the top of the exposed surface of the applied and cured finish (see Figures 12 and 13). Once positioned properly in this location, it can effectively scatter light and the amount of microparticulate will determine how much light is scattered,

Figure 13

Microparticulate (flatting additive) migration during UV cure to the applied coating surface



allowing the formulator the ability to target any given surface sheen.

Commonly, the microparticulate matter, or flatting additive, is a silica that has a higher density than the UV-curable coating liquid composition that it resides in. This higher density contributes to its tendency to settle on the bottom of the liquid UV-curable coating container during prolonged storage. Without going into extensive detail on how we accomplish migration of this heavier microparticulate to the surface where it can effectively scatter reflected light, suffice it to say that there are a number of process variables that affect this migration.

Here are some key factors that influence gloss:

- *The thickness of the applied UV coating layer*
  - Thicker requires greater distance of microparticulate travel to the surface and under equal process conditions will result in higher gloss
  - Thinner results in lower gloss for the opposite reason of shorter travel distance to the surface
- *The viscosity of the applied UV coating layer*
  - Higher viscosity imparts fluid resistance to the travel of the microparticulate to the surface, and results in higher gloss
  - Lower viscosity facilitates ease of microparticulate travel to the surface, reducing gloss
- *Color of the wood substrate*
  - Darker colors tend to exhibit lower relative sheen values at equal flatting additive concentration versus lighter colors using the same UV process
- *UV cure lamp type and sequence* (gallium with through-cure versus mercury with surface cure tendencies)
- *UV cure lamp radiant power and energy density delivered to the applied UV-curable coating*
- *Process line speed*
  - Line speed is a process variable that interacts with UV-cure lamp power to limit or promote the energy density delivered to the applied UV-curable coating. This will influence gloss expression by influencing the time period allowed for cure.
  - High lamp power, high dose and high speed will result in higher relative sheen values
  - Lower lamp power, sufficient dose and low speed will result in lower relative sheen values

Wood Species Considerations

Wood product manufacturers typically finish multiple wood species. When using 100% UV-curable coatings, however, there are some unique considerations that are important for high-quality, high-performance finishing involving:

- Molding and milling
- Preparatory and intercoat sanding
- Wood moisture content
- Wood temperature

Molding and Milling Operations

The molding and milling of various species is a function most wood manufacturers are very conscious of and usually operate well. The quality of the knives and their degree of sharpness must be maintained to produce quality finishing. Wood is very compressible and dull knives may cut, tear out and push wood fiber down only to reveal adverse characteristics, especially when waterborne stains are applied. Any cross grain, repeat lines equally spaced less than 1" apart is seldom a result of poor finishing, but can be from poor milling.

Preparatory and Intercoat Sanding

In this project, UV-curable clear and stained finishing was achieved by bringing the wood surface up to a sanding quality consistent with 180 grit media. UV-curable paints were best applied to wood surfaces that were prepared with 150 grit media. The increased surface texture or surface area that resulted provided better surface adhesion of the applied UV-curable paint.

Regarding intercoat sanding of the applied 100% UV-curable coatings being used, it was found that the lineal profiles were best sanded using a four-head sanding process:

- **First Two Brushes**—180 grit abrasive nylon sanding brushes; brush heads rotate with and then against the direction of the part.

- **Second Two Brushes**—150 grit sand paper strip brushes with a natural bristle brush backer; first brush uses a 1/8" sanding strip and the second uses a 1/4"; brush head rotation is the same as is used for the nylon sanding brushes described above.

Wood Moisture Content

The wood species being used in this project are considered hardwoods and included basswood, poplar, oak and cherry. Although classified as hardwoods, basswood and poplar are softer and present unique characteristics when processing and finishing that differentiate them from oak and cherry.

The best quality lumber and, ultimately, surface finish was achieved when the moisture content of all species was between 5% and 8%. (Note: This is distinctly different from processing sapwood species which is best processed and finished in the 12% to 18% range to accommodate dimensional problems such as warping and twisting.) Although the bulk moisture content was closely monitored, absorbed surface moisture was an important consideration when using basswood and poplar.

Environmental factors are very important to quality finishing and some affect certain species more than others. In this situation, basswood and poplar (as well as other widely used species such as aspen, birch and other soft hardwoods) can attract moisture rapidly. Any cold storage of lumber can influence the surface moisture of the wood once it is brought into warmer temperatures (moisture will condense on the surface of cold lumber in a warm environment). Adhesion of 100% UV-curable coatings can be compromised when applied to and cured on moist surfaces. Though lumber should always be equilibrated prior to finishing, we found that the finishing operations using basswood and poplar benefited by the use of surface heating prior to UV-curable coating application. The simple addition of a short, in-line, infrared heating zone just prior to coating application worked well for these species.

Wood Temperature

Our knowledge gained from integrating UV-curable coatings at a number of other facilities allowed us to suggest to our customer the advantages of monitoring wood surface temperature and, at times, preheating the wood surface prior to coating application.

All wood must be equilibrated to the actual process environment conditions to reduce the potential for surface finish defects, including:

- Poor surface smoothness
- Blisters
- Pinholes
- Voids
- Fish eyes
- Bubbles
- Gloss variation, etc.

Summary

This was a very intensive project that required effective integration of people, process and chemistry and the project resulted in finished woodwork of unsurpassed quality. Figures 14-16 show sets of the resulting finishes achieved through the vacuum and roll coat processes.

We had a great amount of satisfaction working with a progressive wood products manufacturer and the many individuals involved. This review highlighted process and chemistry and the remaining element in the overall process is people. People are the most important of all three elements we were responsible to integrate. Throughout the entire project, it is accurate to say that we learned as much as we trained those involved in the UV process. It is true that no two facilities are alike.

Figure 14

Vacuum coat 100% UV-curable finishes —white, stained oak and natural oak

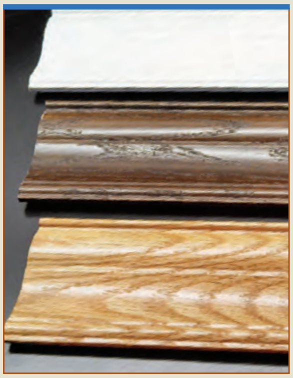
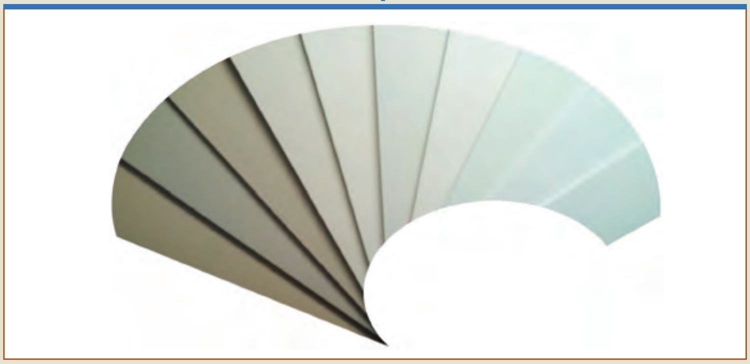


Figure 15

Roll coat 100% UV-curable paint color



They may run the same equipment, but they never run with the same people. People learn at different rates and respond to different motivations. The ultimate result is the mutual pride we all gained—ourselves and our customer—in what we accomplished as an effective team. Training is ongoing as it is a continuum with support, safety presentations and improvements in process and in chemistry.

In conclusion, we undertook a remarkable project with a remarkable customer. The results achieved are typical of our ASAC™ technology concept. There are remarkable opportunities with UV-curable finishes, including a full range of color with paints and stains, and they can be adapted to a variety of application methods. This project considered vacuum and roll coating, but of equal potential are systems for spray, flow, curtain and other methods. For those considering future finishing needs, UV technology should be considered and, above all, work with a partner to help integrate all of the various factors associated with quality finishing.

—Lawrence (Larry) C. Van Iseghem is president/CEO of Van Technologies Inc. in Duluth, Minn.

Figure 16

Roll coat waterborne stains and 100% UV-curable clear finishes