UV-Curable Polyurethane Dispersions: A VOC-Compliant High Performance Solution for Indoor and Outdoor Wood Coatings

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Abstract

Energy curable (UV/EB) coatings have been a staple in wood coatings for some time. The ability to roll coat flat wood substrates using 100% solids energy curable coatings has helped manufacturers meet stringent regulations for chemicals and VOCs and produce durable, quality finishes with excellent appearance. However, for contoured substrates requiring spray applied coatings, such as cabinet doors, it has been a challenge to formulate suitable energy curable coatings without resorting to the use of solvents which increases the coatings VOC, or relying heavily on diluents, which may reduce the performance and aesthetics of the coating. Developing energy curable resins for the wood coatings industry that improve the lifetime, reduce the maintenance and keep the aesthetic appearance of wood is still a challenge for resin suppliers today.

In this paper we show how new high performance water-based UV-curable polyurethane dispersions can address all of these requirements for both indoor and outdoor spray and curtain wood coating applications. Suitably designed novel structures now combine low viscosity, outstanding stain, chemical and scratch resistance with high reactivity in both clear and pigmented systems. Furthermore, there is no need for co-solvents. Some of the polymer structures also have excellent weathering properties.

Water-based radiation curable technology can clearly be considered one of the most promising new developments in the changing landscape of the wood coating market today.

Introduction

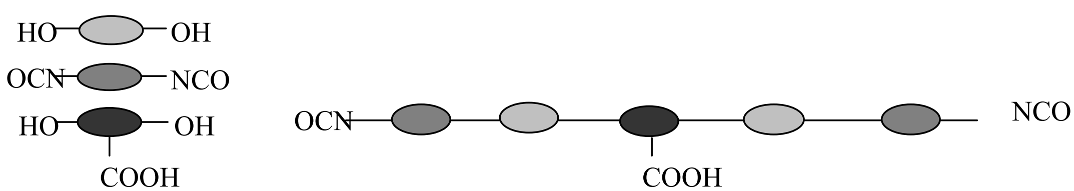
UV technology has been used in wood coatings since the late seventies. Up to now all of these applications have been based on 100% UV curable products, formulated mainly for roller coater application, so it was only possible to coat flat panels. After many developments, UV technology now offers a broad range of 100% UV-curable resins and reactive diluents and has become the preferred technology for industrial parquet coatings, providing excellent adhesion and abrasion performances. The furniture industry needs to coat flat panels, slightly profiled pieces (for example doors) and 3-D pieces such as chairs or assembled furniture. Spray, curtain or vacuum coaters are better suited to these applications than roller coater. Unfortunately, the low viscosity 100% UV curable binders do not perform well in the spray formulations. Many attempts have been made to cut the viscosity with organic solvents with some success; however, a major advantage of UV technology was lost; i.e. very low VOC emission.

During the nineties, UV-curable polyurethane dispersions in water (UV-PUD) were developed. PVC flooring was the first industrial application. The flexibility, adhesion and stain resistance of these coatings made this new technology very successful. The low viscosity and the very low VOC of these dispersions also made them very attractive for spray, curtain and vacuum applications onto wood. Nowadays, a broad range of UV-PUDs are available for primer (adhesion and wood wetting) and for topcoats (good appearance and excellent stain resistance). Binders with good outdoor performance and for pigmented and high scratch resistance coatings have recently been developed.

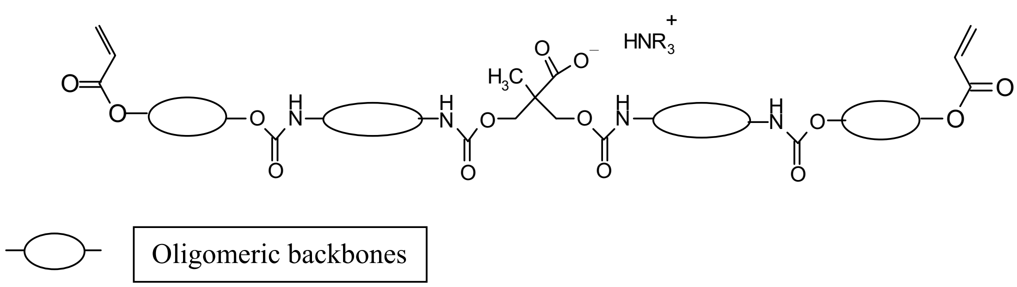
Chemistry and Structure of UV-PUDs

UV-PUDs are synthesized in a multi-step process:

1) Preparation of a polyurethane pre-polymer by reaction of a diol (long and short chain and containing carboxylic function) with a diisocyanate in solvent.



2) Capping of the isocyanate terminated polyurethane with a hydroxyacrylate.
3) Dispersion in water and neutralization of the carboxylic function with a tertiary amine.
4) Stripping of solvent.



Thanks to the broad variety of raw materials, a lot of different UV-PUD structures can be synthesized.

Properties of UV-PUD

Typically, UV-PUDs are low viscosity colloidal dispersions (< 200 mPa.s) with a solid content around 35 to 40%. They can be easily formulated for wood spray applications. They give excellent appearance to open pore finishes. Before UV curing, the water needs to be evaporated completely to avoid blisters, whitening of the film and other defects. After water evaporation, the film may be tacky or tack-free. For the primer coat, this property is not so important. For the topcoat it is preferable to have a tack-free surface in order to avoid dust pick-up and to get a uniform gloss level. UV-PUDs designed for primers have an excellent wood wetting and provide excellent adhesion, even on tropical wood. In topcoats it is possible to obtain excellent chemical and stain resistance as well as very high scratch resistance or outdoor durability.

Formulating with UV-PUDs

As for all UV formulations, the choice of the photoinitiator is important. A liquid photoinitiator can be more easily dispersed than a solid one. A solid photoinitiator must be dissolved in a suitable solvent before addition to the formulation.

A rheology modifier is necessary, even for low viscosity spray application, to give "cohesion" to the liquid film. This will help flow and film uniformity. The rheology modifier needs to be pre-dispersed at 50% in water before adding to the formulation. Wetting and defoaming agents may also be needed.

A typical starting point formulation is given below.

UV-PUD (35-40%)	100.0
Matting agent (100%)	1.5
Wax dispersion (35%)	3
Photoinitiator	1.5
Rheology modifier (50%)	1 - 3
Wetting agent	0.4
Defoamer	0.1

Physical Drying of UV-PUDs

Physical drying is the longest step in the wood finishing process with UV-PUD. A classical drying method is to use air at 35-40°C with a low velocity (0.5 to 1 m/s) for a few minutes in the first stage and then air at 45-50°C with high velocity (jet-dryer). This drying process is far more efficient when using dry air. One of the most efficient drying processes is to combine micro-wave water evaporation with jet-dryers. Infrared technology is suitable on closed pore wood surfaces but will induce bubbles in open pore finishing systems.

Micro-waves drying system

Overview of UV-PUD Range for Wood Coatings

	Products	Chemical Description	Product features	Application	Solids %	Viscosity mPa.s	pH	Particles nm	MFT °C
First generation	UV-PUD 1	Aliphatic UA	Tack-free before UV-cure, after water evaporation Good stain resistance and hardness Good adhesion and flexibility	Basecoat Topcoat	35	< 200	7.5	< 100	< 0
	UV-PUD 2	Aliphatic UA	Tack-free before UV-cure, after water evaporation Very good chemical resistance Good adhesion and hardness	Topcoat	40	< 200	7.5	< 150	< 0
	UV-PUD 3	Aliphatic UA	Tack-free before UV-cure, after water evaporation Excellent stain resistance High hardness and very good scratch resistance	Topcoat	39	< 200	7.5	< 150	< 0
Second generation	UV-PUD 4	Aliphatic UA	Excellent adhesion and wood wetting High flexibility and hardness Water re-emulsifiable before UV cure	Primer Basecoat	40	< 200	7	< 150	< 0
	UV-PUD 5	Aliphatic UA	Tack-free before UV-cure, after water evaporation Excellent outdoor resistance Excellent flexibility Stackable after water evaporation and UV curing	Outdoor Topcoat	35	< 200	7.5	< 100	< 0
	UV-PUD 6	Aliphatic UA	Tack-free before UV-cure, after water evaporation Outstanding scratch and chemical resistances Good reactivity in clear and white pigmented systems	Topcoat	35	< 200	7.5	< 150	< 0

Performance of UV-PUDs in Wood Coatings

Coatings based on UV-PUDs exhibit very low VOC emissions during physical drying and curing and of course, are formaldehyde free.

The colloidal stability (tested at least 10 days at 60°C) of the dispersion is a very important parameter. It allows dispersion of matting agents and other additives in the formulation without the formation of grit and allows longer storage of the dispersion and the formulated product.

The ability to formulate low viscosity coatings for spray or curtain application is one of the key advantages of the UV-PUD technology compared to 100% UV curable formulations. The application equipment is easier to clean when using products which are re-emulsifiable compared to tack-free products (after water evaporation).

The adhesion of coatings based on UV-PUDs to wood is excellent, thanks to the fiber swelling. For high performances finishes such as parquet (mainly primer) or kitchen cabinets (complete UV-PUD system), high scratch resistance (Erichsen pen or "Hamberger" test) is obtained. Typical values are 12 - 15 N (Erichsen pen) or 25 -30 N (Hamberger).

Wood wetting is very important for appearance, especially for furniture finishing. Wood is a living material which may not be transformed to a "plastic like" material. This is particularly true for dark wood species and is illustrated in the next picture.

Left: first coat with UV-PUD 4. Right first coat with UV-PUD 1

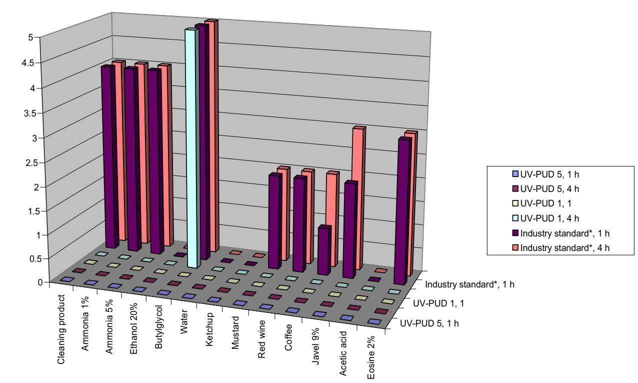
It is also possible to combine UV-PUD 1 with other UV/EB water-compatible materials in order to get a better wood wetting, which lead to improvements in adhesion and appearance.

Outstanding stain and micro-scratch resistance can be obtained with the latest developed UV-PUD 6.

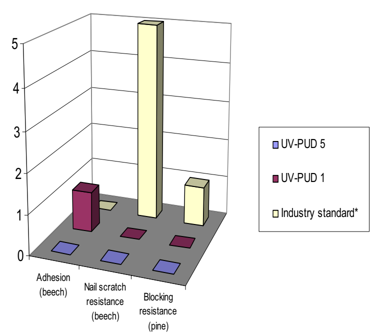
UV-PUD 1 is more easily to formulate than UV-PUD 2 & 3 but has slightly lower chemical and scratch resistance.

UV-PUD 6 combines ease of formulation with exceptional scratch and chemical resistance. It has also a high reactivity (35 m/min with 1 Hg lamp of 80 W/cm compared to 5 m/min for UV-PUDs of the first generation) and is suitable for white pigmented systems. It passes 25 steel wool double rubs (white pigmented film of 110 g/m² wet) while a UV-PUD of the first generation only passes 5 rubs. A clear coating (120 g/m² wet based on UV-PUD 6) has a Persoz hardness of 320 s compared to 230 s for the first generation of UV-PUDs. The level of chemical resistance (DIN 68 861 – EN 12720) is also very high (no visual stain with NH3, red wine, mustard, alcohol 50%, black marker, tar, shoe polish...)

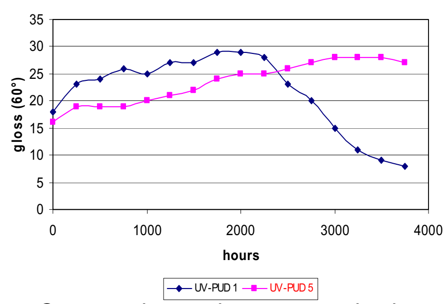
Outdoor performance is obtained with UV-PUD 5. For outdoor exposure, wood needs special protection, especially the wood-coating interface which is very sensitive to the combined action of UV light and humidity. The first coats need to impregnate the wood, and traditional acrylic emulsions are well suited to this purpose. UV-PUD brings advantages for the topcoat: excellent weathering, chemical and physical properties and good blocking with 150 g/m² (wet) instead of 250 g/m² (wet) for a conventional topcoat. These properties are illustrated in the next figures. UV-PUD 5 has a better performance than UV-PUD 1 of the first generation. Chemical, scratch and blocking resistances of both UV-PUDs are superior to conventional water-based acrylic.



Chemical resistance DIN 68 864 (0 = very good, 5 = bad)



Physical properties (0 = very good, 5 = bad)



Comparative ageing on neutral substrate

Conclusions

UV-PUDs cover a very broad range of applications for wood coatings: clear and pigmented, indoor and outdoor. Thanks to their low viscosity, they can easily be applied by spray or curtain coater for non-flat surfaces. The existing finishing lines for solvent (if rust resistant) or conventional water-based can be adapted by adding UV curing equipment. The very low VOC emission is in accordance with the new regulations. UV-PUDs show exceptional properties for wood coatings such as stain resistance, chemical resistance, excellent appearance and very good physical properties.