Demonstration of a No-VOC/No-HAP Wood Furniture Coating System

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Under U.S. Environmental Protection Agency (USEPA) sponsorship, Aero Vironment Environmental Services, Inc and Adhesives Coating Co. (ADCO) teamed to develop and demonstrate a no-VOC/ no-HAP wood furniture coating system. This two-part system consisted, in general, of an epoxy resin emulsion (Part A) and an aqueous solution of a reaction product of certain polyamines and urea formaldehyde ether monomers[1]. The objectives of this project were to develop a new wood coating system that was sufficiently mature for demonstration and to develop a technology transfer plan to get the product into public use. The performance characteristics of this new coating system were excellent in terms of adhesion, drying times, gloss, hardness, mar resistance, level of solvents and stain resistance[2].

In parallel with this demonstration project, surveys were conducted for the South Coast Air Quality Management District (SCAQMD) to gain an understanding of the effort required by the wood furniture industry to change over the water-based coating systems in general. The survey results are presented in this paper including coating acceptance, cost, spray techniques, coating repair procedures, dry times and procedures, spray equipment cleanup and materials and techniques. In addition to the research and development work, a detailed cost analysis has been performed on furniture finished with the new wood coating system. The analysis considers new product introduction decisions such as realistic material cost, capital outlay requirement and labor.

The VOC content of the new system (stain, sealer and topcoat) is less than 10g/l. This system's performance and properties on finished material compared favorably with other low-VOC waterborne systems[2]. The focus of follow-on work will be to adapt this new system to other furniture lines. Also, effort will be spent on testing this new system on kitchen cabinets. Extended technology transfer efforts will be required to encourage widespread usage of the new coating system.

Performance Characteristics

The goal of this study was to demonstrate a new no-VOC/no-HAP wood coating system that will find wide applicability across the wood furniture industry. Efforts were directed at developing a complete wood coating system that would exhibit the following attributes:

- *Contains no VOCs*
- *Contains no HAPs*
- *Is "dry to touch" in 10 minutes or less*
- *Is "dry to handle" in 15 minutes or less*
- *Exhibits acceptable hardness*
- *Exhibits excellent intercoat adhesion with wood top / finishing coat*
- *Exhibits "sandable" characteristics*
- *Contains a demonstrated chemical, water stain and chip resistance comparable to other products for the same general use*
- *Exhibits an acceptable level of wood discoloration*

VOC/HAP Contents

Most wood furniture is finished with nitrocellulose-resin-based coatings averaging 750g/l (6/3lb/gal) VOCs and 375g/l (3.1lb/gal) HAPs. In finishing an average dining room table (4x6'), about 9 kg of VOCs and 4.5 kg of HAPs are emitted[4]. While progress has been made formulating low-VOC coating systems, many use ethylene glycol ethers, which are more toxic than most solvents used with nitrocellulose systems. The SCAQMD/California Furniture Manufacturers Association/ Southern California Edison Cooperative Study[3] of low-VOC wood furniture coatings confirmed that most commercially available water-based system contained VOCs and air toxic compounds.

SCAQMD Method 304[4] (Determination of VOCs in Various Materials) was used to conduct VOC analysis. Method 304 is nearly identical to EPA Method 24[5]. ASTM D 1475[6] was used to determine the density of coatings. Total volatile content was measured by ASTM D 2369[7], and water content was determined by ASTM D 3792[8]. Table 1 summarizes the VOC content and the HAP level using EPA Method 8240 (GC-MS/gas chromatography-mass spectroscopy).

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Wood Panel Testing

Oak was chosen for the fist test because it is a hard wood. Oak is also very forgiving—it contains tannic acid which causes discoloration, and a coarse grain structure that is difficult to fill or obtain good flow out with the higher solids coatings. For the second test, pine was chosen because it is a soft wood. The substrates were lightly sanded before the stain was applied and between each pair of coats. The effect of using stain on the two substrates was obtained. The shade of a stain is affected dramatically by the hardness of the wood. This illustrates how color matching will affect the conversion to a water-based coating. The two parts of the coating were mixed and then applied using a high volume, low pressure HVLP spray gun. Some of the coated panels were cured at room temperature, and the remainder at 120° F (49°C) with no apparent difference in the cured coating. Table 2 summarizes all performance characteristic test results.

- **Hot/Cold Check.** Sanding sealer and top coat were tested in the Weatherometer on the stain coated oak and pine samples. The methods described by ASTM 1211[9] as modified to be used with the Atlas XR-35-A Weatherometer, were followed. The following test cycle was performed:

1. Maintain the relative humidity at 50% throughout the test;

2. Run the test without ultraviolet (UV) radiation;

3. Start the system at 70°F (21°C);

4. Raise the temperature to 120°F (49°C) within 15 minutes;

5. Hold this temperature for one hour;

6. Lower the temperature to minus 5°F (-21°C) within 30 minutes;

7. Hold this lower temperature for one hour;

8. Return the temperature to 70°F (21°C) within 15 minutes (this comprises one cycle which takes three hours); and

9. Repeat this test cycle eight times, which will take 24 hours.

Table 1

VOC and HAP Analysis Results

Measurement	Method	Unit	PQI	Concentration Topcoat	Sanding Sealer	Stain
VOC						
Density	ASTM-D1475	g/cm^3		1.021	0.983	0.9313
Water content	ASTM-D-3792	%	0.1	65	68	79
Volatile content	ASTM-D-2369[b]	%	0.1	61	62	69
VOC content	Calculated	%	0.1	N.D.[c]	N.D.	N.D.
HAP	8240 (GC/MS)					
Acetone		mg/kg	100	N.D.	N.D.	N.D.
Acrolein		mg/kg	100	N.D.	N.D.	N.D.
Acrylonitrile		mg/kg	50	N.D.	N.D.	N.D.
Benzene		mg/kg	5	N.D.	N.D.	N.D.
Bromodichloromethane		mg/kg	5	N.D.	N.D.	N.D.
Bromoform		mg/kg	5	N.D.	N.D.	N.D.
Bromoethane		mg/kg	10	N.D.	N.D.	N.D.
Methyl ethyl ketone (2-Butanone)		mg/kg	100	N.D.	N.D.	N.D.
Carbon disulfide		mg/kg	5	N.D.	N.D.	N.D.
Carbon tetrachloride		mg/kg	5	N.D.	N.D.	N.D.
Chlorobenzene		mg/kg	5	N.D.	N.D.	N.D.
Chlorodibromoethane		mg/kg	5	N.D.	N.D.	N.D.
Chlorethane		mg/kg	10	N.D.	N.D.	N.D.
2-Chloroethyl vinyl ether		mg/kg	10	N.D.	N.D.	N.D.
Chloroform		mg/kg	10	N.D.	N.D.	N.D.
Chloromethane		mg/kg	10	N.D.	N.D.	N.D.
Dibromomethane		mg/kg	5	N.D.	N.D.	N.D.
1,4-Dichloro-2-Butene		mg/kg	100	N.D.	N.D.	N.D.
Dichlorodifluoromethane		mg/kg	5	N.D.	N.D.	N.D.
1,1-Dichloroethane		mg/kg	5	N.D.	N.D.	N.D.
1,2-Dichloroethane		mg/kg	5	N.D.	N.D.	N.D.
1,2-Dichloroethene		mg/kg	5	N.D.	N.D.	N.D.
trans-1,2-Dichloropropane		mg/kg	5	N.D.	N.D.	N.D.
1,2-Dichloropropane		mg/kg	5	N.D.	N.D.	N.D.
cis-1,3-Dichloropropene		mg/kg	5	N.D.	N.D.	N.D.
trans-1,3-Dichloropropene		mg/kg	5	N.D.	N.D.	N.D.
Ethyl Benzene		mg/kg	5	N.D.	N.D.	N.D.
Ethyl methacrylate		mg/kg	10	N.D.	N.D.	N.D.
2-Hexanone		mg/kg	50	N.D.	N.D.	N.D.
Iodomethane		mg/kg	5	N.D.	N.D.	N.D.
Methylene chloride		mg/kg	10	N.D.	N.D.	N.D.
4-Methyl-2-pentanone		mg/kg	50	N.D.	N.D.	N.D.
Styrene		mg/kg	5	N.D.	N.D.	N.D.
1,1,2,2-Tetrachloroethane		mg/kg	5	N.D.	N.D.	N.D.
Tetrachloroethene		mg/kg	5	N.D.	N.D.	N.D.
Toluene		mg/kg	5	N.D.	N.D.	N.D.
1,1,1-Trichloroethane		mg/kg	5	N.D.	N.D.	N.D.
1,1,2-Trichloroethane		mg/kg	5	N.D.	N.D.	N.D.
Trichlorofluoromethane		mg/kg	5	N.D.	N.D.	N.D.
1,2,3-Trichloropropane		mg/kg	5	N.D.	N.D.	N.D.
Vinyl acetate		mg/kg	50	N.D.	N.D.	N.D.
Vinyl chloride		mg/kg	10	N.D.	N.D.	N.D.
o-Xylene		mg/kg	5	N.D.	N.D.	N.D.
m-Oxylene, p-Xylene		mg/kg	5	N.D.	N.D.	5[d]

a. PQL: Practical Quantification Limit

b. This method did not result in evaporation of all the water. D-1475, a GC method, yields a much more accurate measure of water content. As shown VOCs were N.D. and there were no exempt solvents present.

c. N.D.: Not detected or <PQL

d. Likely a contaminant from tape used to seal sample jars.

Using this evaluation method we determined the resistance to checking or cracking of coatings applied to wood substrates when subjected to sudden changes in temperature. Cold check manifest themselves in two ways: long continuous wavy lines either parallel with or at various angles that can be perpendicular to the grain; or innumerable fine lines erratic in direction and length forming a network over a portion or all of the panel. This effect is similar to crazing of the coating film.

On plywood, the direction of the crack often varies because of the stresses set up by other than the top stratum. For this reason, all checks were considered failures, and appropriate notations on the character of the cracks were made to assist in the interpretation. While it is recognized that the cracks in substrates may occur (veneer checking), failures in the coating may be due to action of moisture, cold or both. Checking because of moisture appears along the grain and is characterized by short cracks—usually not more than 0.5" (1.3 cm) long—occurring either singly or in clusters. These lines or clusters may progress along the gain in a discontinuous fashion.

Results: There was no evidence of checking. The coating did not show any sign of failure due to changes in temperature and humidity.

• **Gloss.** When evaluating the appearance of a surface, gloss is an optical phenomenon. The evaluation of gloss describes a surface's ability to reflect direct light. Gloss is often used as criterion for evaluating a product's quality, especially where aesthetic appearance is important. A visual gloss evaluation includes many subjective sources of error and is insufficient. To be objective, an instrument was used to put a measured value on the degree of gloss. However, it must be realized that gloss, as perceived by the human eye, is a subjective sensation, intersection of cuts; the lattice area affected is 5-15%.

- Gt 3/2 B: The coating has flaked along the edges and/or parts of the squares; the lattice area affected is 15-35%.
- Gt 4/1 B: The coating has flaked along the edges of cuts in large ribbons, and/or parts of the squares or whole squares have detached; the lattice area affected is 35-65%.
- Gt 5/0 B: Flaking and detachment are greater than 65% of the lattice squares.

Results: All samples showed a rating of Gt 0/5 B, which is excellent. The coating was very hard and not brittle.

- **Adhesion/Scrape/Mar.** Water-based coatings are more plastic and mar resistant than solvent-based coatings. When scraping pressure is applied to solvent-based coatings, the surface of the substrate tends to scrape off. Water based coatings (being more plastic) are tougher and tend to indent the substrate, actually deforming the coating surface without rupturing it.

A modified version of ASTM D 2197[12] was followed. This evaluation method covers the determination of the adhesion of coatings when applied to smooth, flat panels. After complete curing, the adhesion/scrape/mar resistance was determined by pushing the panels beneath a round stylus of loop with increasing pressure until marring or the coating was detected. This method has proven useful in characterizing a coating's degree of hardness, especially for relative ratings of a series of coated panels exhibiting significant differences in mar resistance.

The value given is the weight in grams applied to the stylus before marring was detected. The result of the tests are relative. The mean value of the weight amount to mar the surface of solvent-based coatings was 300g. From previous studies comparing the mar resistance with solvent-based coatings, we concluded that any coating which mars at 300g or higher is satisfactory.

Results: All samples were tested at 1000g (maximum capacity of the test equipment) and showed no marks. In tests performed at Southern California Edison's Customer Technical Assistance Center[3], solvent-borne coatings tested at 300g showed marks. Since water-based coatings were being compared to solvent-borne coatings in that test, 300g was used as a standard. This proved that water-based coatings are more than three times as durable

Table 2

Coating Properties & Performance Characteristics Test Results

Measurement	*Method*	*Oak Veneer with Stain Sealer and Topcoat*	*Pine Solid with Stain Sealer and topcoat*
Pencil hardness	ASTM D 3363	2H	2H
Gloss	ASTM D 523	26.8, 29.5, 28.2, 32.2	54.5, 50.3, 50.7, 41.0
Parallel groove adhesion	ASTM D-3359	Gt 0/5B (excellent)	Gt 0/5B (excellent)
Adhesion/Scrape/Mar	ASTM D 2197	No marks at 1000g (excell.)	No marks at 1000g (excell.)
Hot/Cold check	ASTM D 1211	No checking or cracking	No checking or cracking
Household chemical	ASTM D 1308		
Catsup		no effect	no effect
Mustard		very slight yellow stain	very slight yellow stain
Coffee		no effect	no effect
Acetone		no effect	no effect
Margarine		no effect	no effect
Vinegar		no effect	no effect
Cold tap water		no effect	no effect
Hot tap water		no effect	no effect
Nail polish remover		no effect	no effect
Drying time (air dry)	ASTM D 1640	30 minutes	30 minutes
Water resistance	ASTM D 1308	no effect	no effect
Printing/Block	ASTM D 2091	no effect	no effect
Orange peel	visual inspection	no indication of	no indication of
Aesthetics	visual inspection	good	good
Color		good	good
Clarity		good	good

a Measure change in pencil hardness one hour after recovery from water.

and visually observed differences cannot always be measured physically using glossmeters. The methods described in ASTM D 523[10] and the BYK Tri-gloss meter instructions were followed. This evaluation was performed on all substrates.

The gloss was specified to be a 65° sheen on a 60° scale. Variations of the gloss readings with the same coating on different substrates resulted from the absorptivity of the coating material into the substrate: the higher the gloss, the more the imperfections. A satin sheen tends to hide imperfections in the coating and makes the coating look better. On the other hand, it can also make the coating look milky. The instrument was calibrated with black gloss at a 60° incidence.

Results: Four gloss reading were taken on each panel *(see Table 2)*, spaced evenly and vertically down the center of each panel. The panel having a softer grain had a lower gloss reading. The panels with the higher gloss reading could have had a heavier coating on them than the panels with the lower gloss reading. If another coat of a topcoat was applied to the panel, the readings would be higher.

- **Parallel Groove Adhesion.** If a coating is to fulfill its function of protecting or decorating a substrate, it must adhere to it for the expected service life. Surface preparation, or lack of it, has a drastic effect on a coating's adhesion. Evaluating adhesion to different substrates, or in different coatings to the same substrate, is of considerable importance to the industry.

Using the ASTM D 3359[11] evaluation method, the adequacy of coating adhesion was determined. A tool which cuts parallel grooves was used to cut a cross-hatch pattern in the coating down to the substrate, then tape was applied over the grooves and removed. After removing the tape, the cross-hatch and tape were inspected to detect any flakes lifted at the edge of the cuts. The appearance of the crosshatches were then rated against the standards listed below.

The Gt numbers shown below are the ratings given by ASTM. However, for the purpose of this test, anything worse than Gt 1/4B was noted as a failure. Any reading equal to or higher than Gt 2/3B was considered as having insufficient adhesion properties for most uses in the furniture industry:

- Gt 0/5 B: The edges of the cuts are completely smooth; no lattice squares are attached.
- Gt 1/4 B: Small coating flakes are detached at intersections less than five percent of the lattice area is affected.
- Gt 2/3 B: Coating flakes are detached along the edges and/or at

Table 3
NUMBERS & TYPES OF COMPANIES CONTACTED

Category	Type of Business	No. of Manufacturing Cos. in the So. Coast Air Basin	Companies Contacted	Using One or More Water-based Coatings	No Water-based Coatings Used
A	Household furniture	297	49	6	8
B	Office furniture	18	16	3	3
	Totals	315	65	9	11

as typical solvent-borne coatings.

• **Orange Peel.** Orange peel is an irregularity in a paint film's surface which results from the wet film's inability to "level out" after being applied. Orange peel appears as an uneven or dimpled surface to the eye, but usually feels smooth to the touch.

Results: There was no indication of orange peel on the samples. The coating flowed out nicely.

•**Household Chemicals.** The ASTM D 1308[13] method was followed to test coatings using household chemicals. This evaluation method was used to determine the effect household chemicals have on organic finishes. Household chemicals may result in objectionable alteration of a surface; e.g., discoloration, change in gloss, blistering, softening, swelling or loss of adhesion. Resistance to various home-use chemicals is an important characteristic of organic finishes. Test methods provide the means by which the relative performance of coating systems may be evaluated. The open-spot evaluation test method was used—the reagent was placed directly on a surface and allowed to remain uncovered for an hour. The surface was then examined for a chemical reaction. It must be noted that chemicals such as acetone and nail polish remover do not remain (they evaporate quickly) on a surface for an hour. However, the time they do remain wet on a surface is normally long enough to mar it. In past tests with other coatings, they either melted the coatings, or turned them white.

The household chemicals used were catsup, mustard, coffee, acetone, margarine, vinegar, nail polish remover, and cold and hot tap water. The ratings were: 1, no effect; 2, slight effect; 3, medium effect; and 4, heavy effect.

Results: Only mustard showed a very slight yellow stain on coated wood panels. The remaining chemicals showed no effect at all.

• **Aesthetics.** The untrained eye knows when it sees a good finish, but can't explain why. Each panel was inspected and a value placed which best described the appearance, color and clarity of each substrate's coating. Descriptors, used to best define how the coated panels looked, are described below.

•Appearance. The appearance was judged on 10 characteristics which would best described the coating's flowing characteristics. They were: good, graininess, mottled, orange peel, flow problems, blistering, checking, cracking, flaking and filling.

•Color. The color was judged on six different characteristics: good, bleached, red, green, natural and yellowing.

•Clarity. Clarity was judged on two different characteristics: good and milky.

Results: The coating system had a nice slightly amber color. Both oak and pine panels received "good" ratings for appearance, color and clarity.

• Other Performance Tests. Pencil hardness (ASTM D 3363)[14], drying time (ASTM D 1640)[15] and printing /blocking (ASTM D 2901)[16] tests were also performed. Results are summarized in Table 2.

THE SURVEY

A survey was conducted jointly by SCAQMD and Industry Working Group comprised of representatives from coating manufacturers, wood coaters, spray equipment vendors and

Table 4
SURVEY RESULTS *(For Companies That Completed Survey)*

Question	Answer				
Are your finishing process:					
Less than six coating steps?		14			
Six or more coatings steps?		8			
Is the final product satisfactory?					
Depth of gloss	Yes/No/Don't Know:	9/9/0	Overall quality appearance	Yes/No/Don't Know:	9/10/0
Gloss	Yes/No/Don't Know:	12/6/1	Finish defects	Yes/No/Don't Know:	10/7/0
Solvent resistance	Yes/No/Don't Know:	11/5/0	Color/stain matching	Yes/No/Don't Know:	10/7/0
Durability	Yes/No/Don't Know:	11/6/0	Clarity	Yes/No/Don't Know:	11/7/0
Fade resistance	Yes/No/Don't Know:	10/8/0	Repairability	Yes/No/Don't Know:	9/9/0
Shipping durability	Yes/No/Don't Know:	9/7/0	Material cost	Yes/No/Don't Know:	6/12/0
Hardness	Yes/No/Don't Know:	10/7/0	Labor cost	Yes/No/Don't Know:	7/10/0
Drying time	Yes/No/Don't Know:	5/13/0	Safety	Yes/No/Don't Know:	16/3/0
Grain raising	Yes/No/Don't Know:	9/7/0	Overall cost	Yes/No/Don't Know:	6/12/0

How are you repairing low-VOC coatings?

Answers: (Do you use a wash/barrier/tie coat?) Not using water. Sand and touch-up stain, respray topcoat. Testing has been very limited. Can't fix a spot. Have to do a whole piece, wash off, and start over. Mohawk aerosol stain lacquer and sealer.Requires complete refinishing. It's more difficult. No tie coat. We must use a tie coat. Sand and recoat with washcoat. Strip and refinish.

Are additional steps in your manufacturing process necessary in order to use the low-VOC coatings you be tried? Yes/No/Don't Know: 11/7/0

Have the low-VOC coatings caused an increase in line rejections? Yes/No/Don't Know: 6/4/1

continued on next page

Table 4

SURVEY RESULTS (CON'T)

What type of application equipment are you using?

	Stain	Sealer	Topcoat	Other
HVLP	15	17	17	3
Air assisted airless	1	1	1	0
Manual	14	13	13	3
Wiping	1	0	0	1

Do you experience any problems cleaning the equipment		Yes/No:	4/13
Does you coating need to be force dried?		Yes/No	8/9
Do you have ovens or drying equipment?		Yes/No:	8/13
	Gas	3	
	Electric	1	
	IR	4	
	UV	0	
Will additional employees be required because of the implementation of low-VOC coatings?	Yes/No/Don't Know:	9/6/2	
Is additional warehouse or floor space required for the drying or curing of the low-VOC coating before packaging?	Yes/No	11/9	
Approx. how much will the conversion to low-VOC cost?		$2,000-$3 million	
About how much has it cost so far?		$2,000 -over $2 million	
Do you have conveyor? If so, at what line speed does it run?		Yes/No	7/13
	Line speeds:	10-12 fpm	
		Varies	
		6.5 fpm	
		14 fpm	
		10-15 fpm	
Does the customer find the finish acceptable?	Yes/No	7/7	
Rate customer response to low-VOC coatings	Highly positive	0	
	Positive	4	
	No Comment	8	
	Somewhat negative	2	
	Negative	4	
	Don't know	2	

consultants to eliminate leading questions and to avoid any perceived biases. The objectives were to survey wood furniture manufacturers and determine:

- *The extent of industry's conversion to date to compliant wood coatings;*
- *The degree to which compliant wood coatings are realistically available for implementation;*
- *Existing problems with currently available technologies;*
- *Consumer acceptability of furniture finished with water-based wood coating systems; and*
- *Relative advantages and disadvantages of available water-based wood coating systems.*

The survey was based on a detailed questionnaire[17] covering the spectrum of issues faced by the wood coater's industry that might affect their ability to achieve compliance with low-VOC coatings. It was amended several times by the SCAQMD staff and a Industry Working Group. The SCAQMD provided the survey team with a computerized list of company names, locations, contact persons, phone numbers, permit numbers and Standard Industrial Classification (SICs). Tables 3 and 4 summarize the survey results.

CONCLUSIONS

Some water-based coatings are currently available on the market[20]. However, they work well only in some applications, and cannot be applied across all finishing lines.

The physical characteristics of the new wood coatings are excellent. They passed all tests successfully. Laboratory analysis confirmed that this new coating has no VOCs and no HAPs.

The keys to successful conversion from solvent- to water-based coatings are staff training and technical support from the coatings manufacturers. Personnel may need retraining on spraying techniques of water-based wood coating applications[19]. When using water-based coatings, additional finishing steps including sanding and force drying may be required. Increased labor costs may result because of the additional finishing steps. The new coating system should find wide applicability across many segments of the wood furniture industry. ■

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