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RESEARCH AND PRODUCT DEVELOPMENT OF LOW-VOC WOOD COATINGS: FINAL REPORT

by

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FOREWORD

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E. Timothy Oppelt, Director
National Risk Management Research Laboratory

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ABSTRACT

Traditional wood furniture coating technologies contain organic solvents which become air pollutants as the coating cures; mitigation by add-on control devices would be energy intensive. Air emissions can be reduced through the pollution prevention approach of shifting to low-VOC coatings, avoiding the energy penalty.

In this project, a new low-VOC wood coating technology, a two-component, water-based epoxy, was evaluated by determining its performance characteristics, conducting application and emissions testing, and assessing the cost benefits for energy conservation and air pollution reduction. Polymer composition variations of the basic epoxy polymer in combination with several curing agents were conducted.

The resulting top coat was as good as or better than other low-VOC waterborne wood furniture top coats for adhesion, gloss value, dry time, hardness, level of solvents, and chemical and stain resistance. The VOC content of the clear and the white pigmented top coats was less than 10 g/l. Cost of this low-VOC wood coating is comparable to other low-VOC coatings. Improved dry times was identified as a critical area for product improvement. A marketing plan was developed. At least one major coatings manufacturer expressed interest in participating in a product feasibility study.

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ACKNOWLEDGMENT

This report was prepared by Eddy W. Huang[a] of AeroVironment, Inc., for SCAQMD's Planning & Technology Advancement Office and U.S. EPA's Organics Control Branch. The project officers were Ranji George of SCAQMD's Planning & Technology Advancement Office and Robert McCrillis of U.S. EPA's Organics Control Branch.

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a. The majority of the work on this project was completed while the author was employed by the Center for Emissions Research and Analysis, City of Industry, CA.

1.0 INTRODUCTION

It is estimated that the annual U.S. market for wood coatings is approximately 240,000 m^3 (63 million gallons)[1]. If one assumes an average VOC content of 600 g/l (5 lb/gal), 146 million kilograms (315 million pounds) of volatile organic compounds (VOCs) are emitted into the air each year from the use of presently used water-borne and solvent-borne systems for coating wood. The use of "VOC-free" formulations where possible would reduce such air pollution.

The South Coast Air Quality Management District (SCAQMD) Rules 1104 and 1136 - Wood Products Coatings require reduction of VOCs from such sources. It is estimated that SCAQMD-wide compliance with these rules would reduce VOC emissions by about 18 Mg (20 tons) per day through a gradual shift from high to low VOC coatings. By phasing in low VOC coatings, instead of requiring installation of add-on controls, SCAQMD believes that furniture manufacturers will be able to comply with SCAQMD's rules without increased costs. To remain competitive in the regulated South Coast Air Basin, coatings formulators and furniture manufacturers have expressed interest in seeing further developments in low VOC coatings technology. SCAQMD Rule 1136 currently limits the VOC content to 680 g/l of clear topcoat and 600 g/l of pigmented coating, less water and less exempt compounds. A final compliance limit of 275 g/l for both clear topcoats and pigmented coatings is currently set to take effect by July 1, 1995[2].

The worldwide coatings market is estimated to be in excess of $34 billion annually. The U.S. market is about $14 billion segmented in three main categories: (1) Architectural Coatings (AC); (2) Product Coatings used by original equipment manufacturers (PC-OEM); and (3) Special Purpose Coatings (SPC). In most markets, customers' needs are being satisfied by a relatively small number of coatings companies, many with sales approaching $1 billion. A significant number of coatings operations are part of large chemical groups such as AKZO Nobel, Ashahi, BASF, DuPont, ICI, Mitsubishi, and PPG Industries. The industry also includes a number of very large independents, like Beckers, Jotun, Kansai, Lilly, Nippon Oil & Fats, Nippon Paint, Reliance, Sadolin, Sherwin Williams, and Valspar. The profile of the coatings industry and the markets it serves has undergone dramatic change in the last decade. The strongest thrusts have been forced by such things as huge business realignments, consolidations and reductions in the number of coatings companies, and the impact of environmental compliance.

The U.S. Environmental Protection Agency (EPA) is implementing regulations designed to minimize the emissions of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs). EPA actions will affect the marketing of coatings, and the organic and inorganic binders which are widely used in the industry. Some paint manufacturers, which have previously switched to coatings thinned with "conforming" solvents such as chlorinated hydrocarbons, will have to find other alternatives since these chlorinated solvents are now listed as HAPs.

There is an increasing use of durable water-borne and water reducible coatings which are in fact free of so-called "keying agent" or "coalescing agent" solvents. Finally, there is a resurgence of interest in solvent-free coatings such as powder and radiation-cure (powder and radiation cured coatings can still emit VOCs during curing, however), which would probably not have reached such research intensity were it not for the air, water, and toxicity legislation on the state and federal levels.

The wood coating industry can be separated into two categories having different requirements with respect to application technique[3]. These are flat stock coating and the coating of three dimensional objects. Coating of flat stock is usually done on a continuous coating line of some type, while more complicated three dimensional objects, such as furniture, usually require spray application and batch drying. The kitchen cabinet industry uses nitrocellulose (N/C) for the high end products and conversion varnish/conversion lacquer for the bulk of its finishing needs. Conversion varnishes and lacquers contain up to 50% of urea or melamine formaldehyde resins which are only partially cured at the low temperatures allowable for wood surfaces; thus there is a significant level of free formaldehyde emanating from the coating throughout its use life. Formaldehyde has been designated by the EPA and California Air Resources Board as a suspected carcinogen. The N/C must be replaced to meet VOC regulations and the uncured urea/melamine formaldehyde containing coatings replaced to meet the very low ppm of "free formaldehyde" requirements.

Water based products have been introduced to much of the lumber industry to replace the high VOC materials previously used on plywood, hardboard, particle board, and regenerated wood-finger jointed wood products. These products, however, exhibit lowered performance properties such as hardness, toughness, adhesion, and solvent and stain resistance. Their second weakness is in energy consumption (i.e., they require long time/temperature exposure for cure). They may or may not meet the free formaldehyde requirements which become more exacting each year.

The purpose of this study was to evaluate a new low-VOC wood coating technology by determining its performance characteristics, conducting application and emissions testing, and assessing the cost benefits for energy conservation and air pollution reduction. The low-VOC wood top coat selected for this demonstration project was a two-component, water-based epoxy coating developed by Adhesive Coatings Co. (ADCO), San Mateo, California. Polymer composition variations of the basic epoxy polymer in combination with each of several curing agents were conducted.

The resulting top coat showed excellent performance characteristics in terms of adhesion, gloss value, dry time, hardness, level of solvents, and chemical & stain resistance. The VOC contents of both the clear top coat and the white pigmented top coat were less than 10 g/l. The coating performance characteristics, and properties in finished material were compared with other low-VOC waterborne wood coatings. Finally, the cost benefits of this low-VOC wood coating, critical areas for product improvement, market development plan, and future research work are addressed in this report.

The complete absence of organic solvents means that this new coating system is not only less hazardous to use but emits no detectable VOCs and therefore does not contribute to air pollution. This new two component water-based epoxy wood coating system has the potential to set a new standard and therefore replace a very significant share of current organic solvent systems in use.

This new low-VOC coating's high gloss and excellent chemical resistance properties are ideal for the wood manufacturing industry for flat stock, for particle, chip, and wood flower products; spray primers for door skins; and finishing systems for interior wood products such as furniture and kitchen cabinets. This material can be manufactured using readily available raw materials and standard resin manufacturing equipment without polluting the atmosphere.

Several large companies that manufacture and supply products used in the wood coatings industry have been contacted. The product marketing discussions have centered on how best to commercialize specific ultra-low VOC finished coating applications. Discussions are underway with two major corporations, both of which are worldwide suppliers of industrial products and services to the coatings, adhesives, and polymer industry and recognized as leaders in providing coatings and ancillary products for the wood industry.

2.0 PROJECT DESCRIPTION

This new wood coating system consists of an epoxy component (Part A) and an amine curing component (Part B). The complete absence of organic solvents means that this new coating system is not only less hazardous to use but emits no detectable VOCs and therefore does not contribute to air pollution. The ultra low VOC content of these new wood coatings was confirmed by tests at the Center for Emissions Research & Analysis (see Table A-1 and A-2). This new two component water-based epoxy wood coating system has the potential to set a new standard and therefore replace a very significant share of current organic solvent systems in use.

2.1 Coating Characteristics:

The most important properties for low VOC coating technologies are as follows:

* "Dial-a-Cure" (control cure speed through selection/matching of curing agent)
    - ultra-fast cure (air cure in minutes)
    - high speed application (forced cure in seconds)

* Friendly to adverse application conditions
    - cures under broad temperature range
    - cures on wet or dry surfaces

* Liquid
    - water emulsions with water as the continuous phase, no solvents, no keying

agents, no film coalescing aids present or required
- high solids

* Environmentally sound
  - water reducible & water clean-up of materials
  - no solvent (low VOC)
  - no or very low free formaldehyde
  - no free isocyanate

The attractive coatings characteristics noted above make this new two component water-based epoxy coating a potential replacement for solvent-based systems.

This new ultra-low VOC wood coating system is a high performance, two-part, chemically cured, water reducible, fast drying, epoxy product (can be used as a sealant and as a high gloss, durable top coat that gives a lacquer like, clear finish). It has the following performance properties:

(a) Less than 10 g/l (0.12 lb/gal) VOCs (Method 24 detection limit is 10 g/l),

(b) Liquid with rapid initial drying characteristics upon application,

(c) Hardness,

(d) Flexibility, and

(e) Chemical resistance.

2.2 Technical Approach:

The coating development steps were to make the necessary formulation adjustments, continue with application testing to improve the product characteristics, and overcome the shortcomings. The goal of the project was to develop a wood coating system that will set new industry standards for VOC levels.

The results of the research procedures and laboratory tests were documented and written status reports were prepared detailing the work completed to date along with the identification of areas that may require further investigation.

The technical approach centered around the following activities:

1. Work towards reformulating ADCO's patented epoxy polymer in combination with different curing agents.

2. Identify those compositions that yield the best overall coating performance in terms of gloss value, drying time, hardness/flexibility, and chemical and stain resistance.

3. Conduct the emission tests required to determine whether the compositions selected have less than 20 g/l VOCs.

4. Formulate emulsions with white pigment for those compositions that meet the performance criteria and emissions limits.

5. Identify those pigmentations that yield the best overall coating performance in terms of gloss value, drying time, hardness/flexibility, and chemical and stain resistance.

6. Conduct the emission tests required to determine whether the pigmentations selected have less than 20 g/l VOCs.

7. Prepare different finished wood panel coupons, both clear and pigmented, to demonstrate finished coatings that meet the performance criteria and emissions limits.

8. Assess the market acceptance by a written survey and develop two annual marketing reports to summarize the survey results, manufacturer acceptance, cost benefits, and any application limitations.

2.3 Task Description:

The program for making formulation adjustments and undertaking the necessary application testing to meet the desired product characteristic goals were outlined in the following tasks:

Task 1 - Formulation variations

Polymer composition variations of the basic epoxy polymer in combination with each of several curing agents were conducted. The resulting emulsion was analyzed through laboratory tests to measure gloss value, drying time, hardness/flexibility, level of solvents, and chemical and stain resistance. All test results were documented.

Product coating characteristic criteria used in this project included but are not limited to:

1. The product will contain VOCs < 20 g/l.

2. The product will have a gloss value in the 90-100 range as measured on an 80

degree gloss meter.

3. The product will "dry to the touch" in 10 minutes or less and "dry to handle" in 15 minutes or less for temperatures in the range of 45 to 60°C with a relative humidity not to exceed 80%.

4. The product will have a demonstrated pencil hardness of at least 2H.

5. The product will have a demonstrated chemical, water stain, and chip resistance comparable to other products for the same general use.

Work on variations of the patented epoxy polymer in combination with different curing agents was finalized. The synthesis of the resin into a new resin was completed and was followed by the emulsification of the product in water. Analysis was structured by selecting those additional curing agents not previously evaluated but which were known to be sufficiently reactive to achieve proper film formation and acceptable properties. Each resulting film was characterized as to its properties.

Task 2 - Variations in pigmentation

An emulsion was formulated with white pigment for the best epoxy polymer/curing agent ratios selected in Task 1. Laboratory tests were conducted to measure gloss value, drying time, hardness/flexibility, level of solvents, and chemical and stain resistance. All test results were documented.

Task 3 - Preparation of finished coating samples

The existing two-component spray application system developed by Binks Manufacturing Inc. was modified and the application of the coatings was evaluated to determine if it meets the production requirements of wood furniture manufacturers. The results were shown in Appendix B.

Cure conditions including curing rate, extended pot-life, and rheology modifications to include use of thickeners in the formulation for adjusting the flow of coatings will be evaluated. Both "clear" and "white" finished wet samples for emission testing will be prepared utilizing a two-component variable ratio spray application gun.

Task 4 - Market development

Several wood furniture manufacturers and coating suppliers were contacted to identify wood coating concerns, current application methods, costs, and critical areas for product improvements. Marketing information related to the wood coatings market was collected. The market segments in turn are further segmented into wood furniture, kitchen cabinets, new case goods, plywood (hardboard), regenerated wood products, flat stock finishes, and specialty finishes. This information was reviewed to establish what specific data still need to be collected and how they should be used in structuring the planned market survey of wood coating suppliers.

3.0 RESULTS OF LABORATORY DEVELOPMENT

Polymer variations of ADCO's basic EnviroPolymer (A) in combination with each of several proprietary curing agents (B) were conducted. All combinations contained low or no VOCs. Up to eight different ratio's were evaluated for each combination and the best ratio observed was then selected for further evaluation by applying this coating on solid oak.

Four variations of EnviroPolymer A-1 (EP 180-60), A-2 (EP 200-60), A-3 (EP 510-60), and A-4 (EP H-60) were used in this project. Four proprietary curing agents B-1 (80-70), B-2 (65-71), B-3 (65-99), and B-4 (81-93) were identified as being the most likely to yield promising results. The initial ratings used to identify the most promising ratios for further evaluation were (1) excellent/very promising, (2) good/somewhat promising, (3) fair/possible, and (4) poor/unlikely.

Formulation A-1/B-2 and A-2/B-1 were judged to be the most likely to yield promising test results when applied to a substrate for further determination of the coatings performance characteristics (dry time, gloss, parallel groove adhesion, scrape/mar, chemical and stain resistance).

TABLE 1. POLYMER/CURING AGENT SCREENING MATRIX

	A-1	A-2	A-3	A-4
B-1	Good	Excellent	Poor	Poor
B-2	Excellent	Good	Fair	Poor
B-3	Good	Good	Good	Good
B-4	Good	Good	Good	Fair

Dry time was measured as the amount of time that was taken for the coating to harden before it can be sanded and re-coated. To be objective, a gloss meter was used to put a measured value on the degree of gloss. The method described in ASTM D 523-89[4] was followed.

Evaluation of adhesion to different surface treatments, or different coatings to the same treatment is extremely important to the furniture manufacturing industry. The method described by ASTM D 3359-93[5] was followed. After parallel grooves were cut into the coating, tape was applied over the grooves and removed. The cross-hatch pattern was inspected through a magnifying glass and rated against the standards. Gt 0/5B was the best rating followed by Gt 1/4B, Gt 2/3B, Gt 3/2B, Gt 4/1B, and Gt 5/0B.

A modified ASTM D 2197[6] was followed to differentiate the degree of coating hardness. After complete curing, the scrape/mar resistance was determined by pushing the panels beneath a round stylus or loop that was loaded in increasing amounts until marring of the coatings was detected.

Resistance to various household chemicals is an important characteristics of organic finishes. The methods described by ASTM D 1308-87[7] were followed. This evaluation covers the effects household chemicals have on organic finishes such as discoloration, change in gloss, blistering, softening, swelling, and loss of adhesion.

A cooperative study on the evaluation of low VOC coatings for wood furniture showed several water based clear topcoats met the VOC content requirement of 275 g/l[8]. The performance characteristics of the new ADCO low-VOC coating are compared with those of other low-VOC waterborne coatings in Tables 2 and 3.

TABLE 2. PERFORMANCE CHARACTERISTICS OF LOW/NO-VOC COATINGS

MANUFACTURER/ TOPCOAT	ADHESION	DRY TIME (minutes)	GLOSS 60^{O} SHEEN	SCRAPE/MAR (g)
ADCO TOPCOAT	GT 0/5B	20-25	80.0	1050
AKZO 680-60C018-115 W/B	GT 0/5B	30-35	34.3	300
AMT 01TC-0090-50 W/B	GT 0/5B	30-35	62.0	500
GUARDSMAN 45-1065-40 W/B	GT 0/5B	30-35	46.8	800
LILLY 787W43 W/B	GT 0/5B	30-35	23.9	300
PINNACLE 137-CL-1	GT 0/5B	30-35	79.4	500
SHERWIN-WILLIAMS T70C510 W/R	GT 0/5B	30-35	44.0	500
SINCLAIR WL 14-9	GT 0/5B	30-35	38.6	400
WATERCOLOR TOPCOAT	GT 0/5B	30-35	37.1	600

As seen in Table 2, ADCO's new low-VOC coating showed excellent performance characteristics in terms of adhesion, dry time, gloss, and scrape/mar resistance. The scrape/mar resistance was especially remarkable (twice as good as the average of other waterborne coatings).

SCAQMD method 304-91 (Determination of Volatile Organic Compounds (VOC) in Various Materials) was used to conduct VOC analysis[9]. ASTM D 1475[10] was used to determine the density of coatings. Total volatile content was measured by ASTM D 2369[11] and water content was determined by ASTM D 3792[12].

Most wood furniture is finished with nitrocellulose resin-based coatings averaging 750 g/l VOC and 375 g/l hazardous air pollutants (HAPs). In the finishing of an average dining room table (4 ft X 6 ft), about 9 kilograms of VOCs and 4.5 kilograms of HAPs are emitted. While progress has been made to formulate low VOC coating systems, many of these use ethylene

TABLE 3. CHEMICAL AND STAIN RESISTANCE OF LOW/NO-VOC COATINGS

MANUFACTURER/ TOPCOAT	ACETONE	COFFEE	MUSTARD	HOT TAP WATER	NAIL POLISH REMOVER
ADCO TOPCOAT	1	1	2	1	2
AKZO 680-60C018-115 W/B	3	1	2	1	2
AMT 01TC-0090-50 W/B	2	1	2	1	2
GUARDSMAN 45-1065-40 W/B	2	1	2	1	3
LILLY 787W43 W/B	2	1	2	2	3
PINNACLE 137-CL-1	2	1	2	1	1
SHERWIN-WILLIAMS T70C510 W/R	2	1	2	1	2
SINCLAIR WL 14-9	2	1	2	1	2
WATERCOLOR TOPCOAT	1	1	1	1	2

LEGEND:
1. NO EFFECT
2. SLIGHT EFFECT
3. MEDIUM EFFECT

glycol ethers (see Table 4), some of which are more toxic than most of the solvents used with nitrocellulose systems.

TABLE 4. VOC/TOXIC COMPOUNDS CONTAINED IN WATERBORNE COATINGS

TOPCOAT	VOC (g/l)	AIR TOXIC SUBSTANCES	Wt (%)
ADCO TOPCOAT	<10	NONE	0
AKZO 680-60C018-115 W/B	210	ETHYLENE GLYCOL MONOBUTYL ETHER DIETHYLENE GLYCOL MONOBUTYL ETHER	6.2 3.9
AMT 01TC-0090-50 W/B	240	PROPYLENE GLYCOL N-BUTYL ETHER	1-10
GUARDSMAN 45-1065-40 W/B	270	DIETHYLENE GLYCOL MONOBUTYL ETHER PROPYLENE GLYCOL N-BUTYL ETHER	6.0 3.0
LILLY 787W43 W/B	240	PROPYLENE GLYCOL N-BUTYL ETHER	3.4
PINNACLE 137-CL-1	270	TRIETHYLAMINE ETHYLENE GLYCOL MONOBUTYL ETHER DIETHYLENE GLYCOL MONOBUTYL ETHER	<5.0 3.0 3.0
SHERWIN-WILLIAMS T70C510 W/R	270	ETHYLENE GLYCOL MONOBUTYL ETHER DIETHYLENE GLYCOL MONOBUTYL ETHER	4.8 9.2
SINCLAIR WL 14-9	200	DIETHYLENE GLYCOL MONOBUTYL ETHER	3.0
WATERCOLOR TOPCOAT	100	PROPYLENE GLYCOL N-BUTYL ETHER	1-10

4.0 RESULTS OF MARKET DEVELOPMENT

The wood coating market is segmented by the industry into wood furniture, kitchen cabinet, new case goods, plywood/hardboard/regenerated wood products, flat stock finishes, and specialty product finishes. The wood furniture industry is faced with a dilemma. Other than special small segments of the paper coating industry, wood furniture coatings consume almost 100% of the nitrocellulose coatings produced. The coatings, by the very nature of the high intrinsic viscosity of nitrocellulose, are very low in solids and thus are very high in solvent (i.e., VOCs and HAPs).

The high emission rate has caused the loss of all operating permits in some states and some permits in every state; and wood furniture manufacturers are either moving off-shore or concentrating in the Southeast. Radiation-cure techniques and coatings have made some penetration, although small, because the shape of the item produced does not lend itself to use of existing technology such as UV or EB equipment.

One approach used by the furniture industry to "stay-in business" has been introduced in Europe. This is a modified case goods approach where most of the pieces are prefinished in flat stock, assembled, and then given a final finish and touch-up. Radiation cured coatings are often used to finish the pre-assembled flat stock. The final finish introduces the same VOC problems. The new ADCO low-VOC finishes developed in this project meet the same cure rate without the radiation equipment investment cost, hazard to the eyes of the employees, and skin sensitivities.

In the low-VOC wood coating market research, the needs for new products were discussed with the leaders in the manufacture of regenerated wood products, i.e., particle board, chip board, and wood flower products. There are many product opportunities for application of this new technology. Efforts were focused on such promising possibilities as binders for particle, chip, and wood flower products; spray primers for door skins; surfacers for concrete form boards to replace paper laminate; and finishing systems for interior wood products such as furniture and kitchen cabinets.

It is anticipated that this new low-VOC wood coating will set new industry standards by addressing the following manufacturers' problems:

* The formaldehyde problem. All manufacturers seek low or no formaldehyde exposure to their employees, to the atmosphere surrounding the manufacturing site, or to the customer or user.

* Lower moisture transmission problem. All manufacturers seek to reduce the degradation caused by swelling and warping from changes in product dimension from water evasion.

* Exterior market problem. All manufacturers seek to upgrade their product line to achieve penetration into the exterior product market.

* The down-time clean-up problem. All manufacturers of regenerated board must shut down periodically, for clean-up, so as to reduce the unacceptable green board rejection rate and fire hazard.

* The energy problem. All of the products used by the mills require extensive time/temperature cure or drying cycles. Low temperature or fast air dry would lend improved economics to the industry or provide a large competitive advantage.

* The toxic air emissions problem. Some facilities in the furniture industry may use water-based formulations which contain toxic compounds, most notably, glycol ethers[13]. Most waterborne wood coatings used glycol ethers in their formulations to stay in compliance.

Many resin and coatings manufacturers have done research on very low VOC coatings for the wood furniture industry. Penetration into the market place has been slow due to resistance to change by the furniture manufacturers. Without regulatory pressure, there is no incentive to switch from traditional high VOC nitrocellulose coating systems.

Several wood furniture manufacturers and coating suppliers were contacted to identify wood coating concerns, current application methods, costs, and critical areas for product improvements. Marketing information related to the wood coatings market was collected. This information was reviewed to establish what specific data still need to be collected and how they should be used in structuring the planned market survey of wood coating suppliers. The product marketing discussions have centered on how to commercialize specific low/no VOC finished coating applications resulting from this wood coating project.

Based on the contacts to date with these marketing entities, at least one coatings manufacturer will participate in joint product feasibility studies. Upon development of priority high-value-added products for potential sale and use in the U.S. wood products market as contemplated at the conclusion of this project, ADCO is prepared to enter into either joint venture agreements or licensing arrangements for commercialization of its low-VOC wood products worldwide.

5.0 FUTURE DEVELOPMENT

Low/no VOC "stain" and "sealer" wood coatings need to be developed so that a complete low/no VOC wood coating system will be available for public use. It is desirable to determine the compatibility of coating components (a stain and a sealer to go with the topcoat). The extra developmental work will center on reformulating wood base coatings for a new fast drying, solvent-free sanding sealer. Evaluation of cure conditions will include curing rate, extended pot-life, and rheology modifications for adjusting the flow of coatings.

Follow-on work would focus on adapting this new low-VOC coating to other furniture lines. Some effort might also be needed to combine this new coating with other components (stains and sealers) to comprise complete low/no VOC coating systems. The transition to widespread application across the U.S. and world-wide will require extended technology transfer efforts.

6.0 REFERENCES

1. Huang, E.W., L. Watkins, and R. McCrillis. Formulating Ultra-Low-VOC Wood Furniture Coatings, Modern Paint and Coatings, Volume 83, Number 12, 41-43, 1993.

2. Proposed Amended Rule 1136 - Wood Products Coatings, June 23, 1994. South Coast Air Quality Management District, Diamond Bar, California.

3. Kinzer, K.E. Dual Cure Low-VOC Coating Process, DOE/ID/12692-6, December 1993.

4. D 523-89, "Standard Test Method for Specular Gloss," American Society for Testing and Materials, 1916 Race St., Philadelphia, PA.

5. D 3359-93, "Standard Test Method for Measuring Adhesion by Tape Test," American Society for Testing and Materials, 1916 Race St., Philadelphia, PA.

6. D 2197-86, "Standard Test Method for Adhesion of Organic Coatings by Scrape Adhesion," American Society for Testing and Materials, 1916 Race St., Philadelphia, PA.

7. D 1308-87, "Standard Test Method for Effect of Household Chemicals on Clear and Pigmented Organic Finishes," American Society for Testing and Materials, 1916 Race St., Philadelphia, PA.

8. A Cooperative Study - Evaluation of Low VOC Coatings for Wood Furniture. South Coast Air Quality Management District, Southern California Edison Company Customer Technology Application Center, and California Furniture Manufacturers Association (released in June 1994).

9. Choa, C.B. and S. Hom. Laboratory Methods of Analysis for Enforcement Samples, "Method 304-91, Determination of Volatile Organic Compounds (VOC) in Various Materials," South Coast Air Quality Management District, Diamond Bar, CA, June 1991.

10. D 1475-90, "Standard Test Method for Density of Paint, Varnish, Lacquer, and Related Products," American Society for Testing and Materials, 1916 Race St., Philadelphia, PA.

11. D 2369-93, "Standard Test Method for Volatile Content of Coatings," American Society for Testing and Materials, 1916 Race St., Philadelphia, PA.

12. D 3792-91, "Standard Test Method for Water Content of Water-Reducible Paints by Direct Injection into a Gas Chromatograph," American Society for Testing and Materials, 1916 Race St., Philadelphia, PA.

13. Supplemental Environmental Assessment for: Proposed Amended Rule 1136 - Wood Products Coatings, June 1994. South Coast Air Quality Management District, Diamond Bar, California.

APPENDIX A

Emissions Characterization

TABLE A-1. VOC CONTENT OF CLEAR TOPCOAT	
SAMPLE DESCRIBED AS:	ADHESIVE COATINGS CO. PART A 76-64 (WHITE) PART B 65-99 (CLEAR)
SOURCE:	2755 Campus Drive, Suite 125 San Mateo, CA 94403
ANALYTICAL WORK PERFORMED, METHOD OF ANALYSIS, AND RESULTS:	
SCAQMD Method 304-91: Determination of Volatile Organic Compounds (VOC). Volatile content by ASTM-D-2369, density by ASTM-D-1475, water by ASTM-D-3792 (GC).	
VOCs content VOCs, g/l (of coating) = <10 VOCs, g/l (of material) = <10	

REMARKS:

1. The detection limit for VOCs is 10 g/l.
2. The two products (76-64 and 65-99) were mixed 5 : 1 prior to actual analysis.

TABLE A-2. VOC CONTENT OF WHITE-PIGMENTED COATING	
SAMPLE DESCRIBED AS:	ADHESIVE COATINGS CO. PART A 77-82A (WHITE) PART B 77-82B (CLEAR)
SOURCE:	2755 Campus Drive, Suite 125 San Mateo, CA 94403
ANALYTICAL WORK PERFORMED, METHOD OF ANALYSIS, AND RESULTS:	
SCAQMD Method 304-91: Determination of Volatile Organic Compounds (VOC). Volatile content by ASTM-D-2369, density by ASTM-D-1475, water by ASTM-D-3792 (GC).	
VOCs content VOCs, g/l (of coating) = <10 VOCs, g/l (of material) = <10	

REMARKS:

1. The detection limit for VOCs is 10 g/l.
2. The two products (77-82A and 77-82B) were mixed 10 : 1 prior to actual analysis.

APPENDIX B.

Coating Characteristics and Performance Properties

TABLE B-1. PHYSICAL PROPERTIES OF APPLIED FINISH	
COLOR	Clear or pigmented white
SERVICE TEMPERATURE LIMITS	-18 to 120° C (0 to 250° F). May discolor over 60° C (140° F) after a long period of baking
GLOSS	Clear coating - 90 @ 80° meter Pigmented coating - 75 @ 80° meter
HARDNESS	Pass 2H pencil
FLEXIBILITY	Pass 3 mm (1/8 in.) mandrel bend on steel
IMPACT RESISTANCE	Direct - Pass 3 m/kg (60 in./lb) Indirect - Pass 1.5 m/kg (30 in./lb)
ADHESION	Pass crosshatch 100%
STAIN RESISTANCE (After 1 hour of exposure)	Coating is resistant to: Coffee Grape juice Mustard Ketchup Carbonated cola beverage 100 proof vodka Shoe polish Laundry spot cleaner Detergent 1,1,1 trichloroethane Acetone Petroleum solvents Ethyl alcohol

TABLE B-2. PHYSICAL PROPERTIES IN THE CAN	
APPEARANCE	Milky white, single-phase, creamy liquid
VISCOSITY	Part A: 0.9 Pas (900 centipoise) Part B: 0.9 Pas
pH	5.5 to 7.5
TYPE	Two components: Part A - Epoxy emulsion Part B - Curing agent
DENSITY	Clear: 1030 g/l (8.60 lb/gal) White: 1500 g/l (12.5 lb/gal)
SOLIDS	50% by volume
FLASH POINT	over 150° C (300° F)
SHELF LIFE	> 6 months
VOC CONTENT	< 10.0 g/l (0.1 lb/gal)

TABLE B-3. APPLICATION PROPERTIES	
MIX RATIO	Clear Topcoat: Part A - 5 parts Part B - 1 part White-Pigmented: Part A - 10 parts Part B - 1 part
THINNING SOLVENT	Water
CLEANUP	Warm soapy water
FILM THICKNESS	75-125 μm (3.0-5.0 mils) wet 40-65 μm (1.5-2.5 mils) dry
THEORETICAL COVERAGE	9 m^2/l (360 ft^2/gal) @ 50 μm (2 mils)
DRYING TIME @ 50° C	To touch: 10 min To recoat: 20 min Tack free: 15 min Full cure: 60 min
RECOATABILITY	Very good

APPENDIX C.

MARKET SURVEY QUESTIONNAIRE

Wood Furniture / Kitchen Cabinets

Company Name: ______________________________
Address: ______________________________
____
Name of Contact: ______________ Tele #: ______________

Type of Wood Products Manufactured:

Furniture ______________________________
Kitchen Cabinets ______________________________
Other ______________________________

Types of Substrates Normally Used: ______________________________
____

% Clear Coated _____ % Stain _____ % Solid Colors _____

Manufacturing Process Used:

____
____

Application Method Used:

Spray ☐ Curtain ☐ Roll ☐ Other ☐

Spray Application Equipment Used: Gun Type ______________
Mfg ______________

Steps/Materials Used for Existing Coating Process:

	Step 1	Step 2	Step 3
Stains	☐	☐	☐
Ground Coats	☐	☐	☐
Wash Coats	☐	☐	☐
Sealers	☐	☐	☐
Topcoats	☐	☐	☐

Usage/Physical Properties:

	Annual Usage (gals)	VOC (lb/gal)	Density (lb/gal)	Viscosity	% Solids (wt)
Stains	_____	_____	_____	_____	_____
Ground Coats	_____	_____	_____	_____	_____
Wash Coats	_____	_____	_____	_____	_____
Sealers	_____	_____	_____	_____	_____
Topcoats*	_____	_____	_____	_____	_____

* Please State Major Top coating Concerns:

	YES	NO	Reason
Durability	☐	☐	______________________
Appearance	☐	☐	______________________
Cure Times	☐	☐	______________________
Repair	☐	☐	______________________
Applic. Equip.	☐	☐	______________________
Material Cost	☐	☐	______________________
Mfg. Cost	☐	☐	______________________
Energy Cost	☐	☐	______________________
Handling/Stack	☐	☐	______________________
Health/VOC Lvl	☐	☐	______________________
Other Concerns	☐	☐	______________________

Please State Performance Level of Current System:

		YES	NO		
1.	Appearance Satisfactory?	☐	☐	Typical Gloss Reading:	______________
2.	Durability Satisfactory?	☐	☐	Typical Hardness Value:	______________

		YES	NO
3.	Resistance Satisfactory?		
	Staining Agent A	☐	☐
	Staining Agent B	☐	☐
	Staining Agent C	☐	☐
	Chemical A	☐	☐
	Chemical B	☐	☐
	Chemical C	☐	☐
	Other	☐	☐

		YES	NO
4.	Repair/Touch-up Satisfactory		
	Spot Repair	☐	☐
	Place Repair	☐	☐
	Buff	☐	☐
	Other	☐	☐

5. Cure Times: Dry-to-Touch _____ Min
Dry-to-Handle _____ Min
Stack Time _____ Min
Through Cure _____ Hours

6. Other Shortcomings of Present System:

____

General Comments:

____

Please state performance level for a water-borne system (i.e., would prefer and/or consider using if available):

1. Appearance Requirements: Gloss Level Reading ______

2. Durability Requirements: Typical Hardness Value ______

3. Resistance Requirements:
Staining Agent A ____________
Staining Agent B ____________
Staining Agent C ____________
Chemical A ____________
Chemical B ____________
Chemical C ____________
Other ____________

4. Repair/Touch-up Requirements:

Spot Repair ____________
Piece Repair ____________
Buff ____________
Other ____________

5. Cure Requirements: Dry-to-Touch _____ Min
Dry-to-Handle _____ Min
Stack Time _____ Min
Through Cure _____ Hours

6. Other Shortcomings of Existing Water-borne Systems:

____

General Comments:

____

APPENDIX D.

MARKETING REPORT

RESEARCH AND PRODUCT DEVELOPMENT OF LOW VOC WOOD COATINGS

SCAQMD CONTRACT NO. S-C93101

October 15, 1994

Appendix D

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I BACKGROUND

In excess of 240 million liters or 63 million gallons of water and solvent borne wood coatings are sold in the United States every year. These coatings contain and emit varying degrees of volatile organic compounds (VOC's) -- approximately 125-200 million pounds per each year. South Coast Air Quality Management District (SCAQMD) Rules 1104 and 1136 - Wood Products Coatings require reduction of VOC's from such sources. It is estimated that SCAQMD - wide compliance with these rules would reduce VOC emissions by about 20 tons per day through a gradual shift from high to low VOC coatings By phasing in low-VOC coatings, instead of requiring installation of add-on-controls, furniture and kitchen cabinet manufacturers will be able to comply with SCAQMD's rules without incur ring increased costs. Therefore, in order to remain competitive in the regulated South Coast Air Basin, coating formulators and furniture manufacturers expressed interest in seeing further developments in low-VOC coatings technology.

Currently, Adhesive Coatings Co. (ADCO) a company specializing in the development and commercialization of low-VOC water-based epoxy coatings has developed various wood coating formulations which comply and/or exceed the emissions standards set forth in SCAQMD's Rules 1104 and 1136. Under CONTRACT NO. S-C93101, ADCO continued development work on one of its formulations. It determined performance characteristics, conducted application and emissions testing and worked with selected coatings suppliers to assess for possible commercialization and market acceptance as a wood finish top coating.

II WOOD COATING SUPPLIERS

ADCO, upon development in the laboratory of its low-VOC wood finish coating, contacted several major coating suppliers, each of whom had a significant market position and/or interest in a low or no VOC wood coating. The approach taken with each company was to mutually agree on a joint testing program for investigating ADCO's environmentally friendly water-based epoxy wood coating. Each company was seeking a low VOC wood coating that they could introduce into the marketplace and thereby enhance their market position.

The investigation covered a discussion of current application methods and costs, coating concerns, critical areas for product improvement, and a cost/benefit analysis to establish product performance and economics. Based upon the results of the joint testing program, the level of interest for instituting a market development program to address the marketplace concerns, potential cost benefits and limitations in commercialization of such a coating was ascertained. Over a period of some twelve to 24 months, ADCO worked with five (5) companies. Each of these companies, as a condition for working with ADCO, stipulated that their names must remain confidential.

Company A - Large industrial finishes supplier.

The personnel involved in the program included the Chairman, Senior Vice President, Director of Research and the Senior Project Manager.

Company B - One of the largest international fully integrated coatings companies.

The personnel involved in the program included the Technical Manager for Industrial and Maintenance Products.

Company C - Major fully integrated paint company with a wood finishes division.

The personnel involved in the program included the Manager of the Wood Coating Laboratory and selected laboratory staff.

Company D - International paint company and leading finishes supplier.

The personnel involved in the program included the Marketing Manger and Technical Director of Wood Finishes Division.

Company E - International supplier of coatings resins.

The personnel involved in the program included the Manager of resin products and selected laboratory personnel.

III MARKETPLACE FOR WATERBORNE COATINGS

Opportunities for reduce emissions:

In general, the companies indicated that the demand for changes in finishing materials and manufacturing practices has definitely created the opportunity for them as manufactures to consider more extensive use of the waterborne technologies for kitchen cabinets and furniture coatings. Offering low-VOC products options that meet the long-term regulatory compliance with the appropriate mix of appearance and physical performance is appealing.

The kitchen cabinet/furniture industry uses nitrocellulose (N/C) for the high end or conversion varnish/conversion lacquer for the bulk of its finishing needs. Conversion varnishes and lacquers contain up to 50% of urea or melamine formaldehyde resins which are only partially cured at the low temperature allowable for wood surfaces. Thus, free formaldehyde emanates from the coating throughout its use life. Formaldehyde has been designated by the EPA and California Air resources Board as a suspected carcinogen. The N/C must be replaced to meet VOC regulations and the uncured urea/melamine formaldehyde containing coatings replaced to meet the very low ppm of "free formaldehyde" requirements.

Each of these companies told ADCO that they are striving to reduce their VOC level of existing solvent-borne coatings in response to the proposed MACT standard for the wood furniture industry developed under the Regulatory Negotiation (Reg-Neg) process. The no-VOC wood finish top coat as developed by ADCO was of great interest to them since the furniture and kitchen cabinet markets use over 227 million liters or 60 million gallons of coatings each year in the U.S. alone. The potential to reduce emission is very significant. Because ADCO's water-borne wood finish coating dramatically reduces the level of VOC's, it has excellent potential for long term emission compliance. It does not contain HAP's which are specifically targeted as toxic materials.

The impact of using a no-VOC sealer and topcoat as developed in this project for a "hypothetical manufacturer" of semi-custom kitchen cabinets with an annual usage of 100,000 liters per year of conventional finishing materials is very significant (i.e., 92% emission reduction when compared to current 7-1-95 VOC limits and 83% emission reduction when compared to 7-1-96 VOC limits as shown in Table D-1).

Similarly, the impact of using a no-VOC sealer and topcoat as developed in this project for a "hypothetical manufacturer" of fine furniture with an annual usage of 100,000 liters per year of conventional finishing materials is very significant (i.e., 79% emission reduction when compared to current 7-1-95 VOC limits and 57% emission reduction when compared to 7-1-96 VOC limits as shown in Table D-2).

Performance Requirements:

The companies emphasized that the finishing on wood has two primary purposes - appearance and protection. The appearance must appeal to the customer's vision and sense of touch. The durability must withstand various chemical and physical tests. Durability requirements usually are more stringent with kitchen cabinets and office furniture than with household furniture.

Broadly there are three performance levels available in waterborne systems now on the market.

> Performance Level #1 - Comparable in film properties to nitrocellulose lacquers. These sealers and topcoats are based on typical thermoplastic resin technology. Cost is minimized. Typical systems costs are only incrementally higher than nitrocellulose lacquer. The coatings typical water, detergent and stain resistance are modest but better than nitrocellulose lacquer. However, due to the absence of chemical crosslinking, the ultimate hardness and the speed with which it is developed is limited. Adequate drying temperature must be provided, along with time and air movement to eliminate blocking, mar and print problems.
>
> Performance level #2 - Relies on more sophisticated resin technology and achieves properties meeting the Kitchen Cabinet Manufacturers Association finishing specification. Options are limited. PPG's Aquarlink system is based on sophisticated single resin technology. Cost is nominally higher than nitrocellulose lacquer materials on an overall systems basis. Performance is decidedly improved as is resistance to mar, print and block.
>
> Performance Level #3 - Requires chemical crosslinking or thermoset technology to achieve the highest levels of stain, solvent resistance and hardness. Most are two component materials which exhibit metering, mixing and pot life concerns. There are also single package water-borne spray applied coatings that achieve crosslinking through UV cure. Capital expenditure considerations are a key factor in selection however.

The companies with whom ADCO worked are seeking a low or no-VOC waterborne coating that would fall in Performance Level #3 (i.e., a coating that will have an acceptable gloss finish, have physical properties good or better than what is on the market, have a fast dry to-handle during manufacturing and be cost effective). Currently, they indicated that no such competitive product is in the marketplace.

Concerns with Existing Waterborne Wood Coatings:

In general, they all agreed that water borne coating still "have not yet arrived" based on their experiences to date. The most notable concerns are:

Contamination - Potential contamination of the waterborne coatings with oil-based coatings (i.e., such contamination can cause havoc in a repair situation and bring equipment problems). The window of forgiveness is 25%-40% less than with conventional coatings. Waterborne coatings are difficult to repair after they are cured. They are tough to "wash off".

Appearance - Water-borne coatings in appearance-formulation steps will raise the grain of wood and cause blotchiness (i.e., water introduced into some wood finishing formulas can be tolerated in limited amounts). Current water-borne systems have been able to eliminate the grain raise, roughness or wood swell that occurs when water contacts wood. These problems have been minimized through finishing component formulation adjustments that has resulted in completely acceptable appearance for much of the ready-to-assemble and kitchen cabinet market segments. Hybrid systems are also being used whereby solvent-borne stains and sealers are followed by waterborne topcoats. This method retains the superior wipeability of solvent-borne stains and minimizes grain raise due to the wood's reduced direct contact with water. It should be emphasized that finishing component materials are not always fully compatible. Both solvent borne and water-borne components of any hybrid must be formulated for compatibility.

Temperature/Humidity Variations - Waterborne materials have wide variations in performance and appearance (i.e, primarily caused by varying temperature and humidity conditions during application). Fortunately, through proper polymer formulation, some "user-friendliness" can be built in.

Market Introduction Considerations:

The companies indicated that a market introduction program of such a low-VOC or no-VOC wood coating can only be set up and implemented once acceptable product characteristics have been established and fully market tested. New product introduction decisions must be based on practical material costs, capital outlays and process labor costs and productivity.

In discussions with the personnel of these companies, they indicated that they take into account many factors when they consider selecting a wood coating for market introduction. These factors of course were given differing weights by each company's management. The primary five (5) factors are the following:

(1) Improvements in film performance,

(2) Lower materials cost "per unit finished",

(3) Lower labor costs with improved productivity,

(4) Minimization of changes to the finishing materials and manufacturing processes,

(5) Minimization of capital outlay.

IV COMMERCIALIZATION/MARKET INTRODUCTION

Product Characteristics:

The wood coating formulations developed in ADCO laboratory under SCAQMD Contract No. S-C93101 were used to prepare finished wood samples, both clear and pigmented. These samples were presented to each of the companies to demonstrate the finished wood coating. The wood coatings based on the laboratory tests to date had the following product coating characteristics:

(1) The coating contained less than 20 g/l VOC's.

(2) The coating "dries to the touch" in less 10 minutes or less and "dries to handle" in 15 minutes or less for temperatures in the range of 45^oC to 60^oC with a relative humidity not to exceed 80% RH.

(3) The coating had a demonstrated pencil hardness of at least 2H.

(4) The coating had appeared to have a demonstrated chemical, water stain, chip resistance and gloss levels comparable to other products in the same general use.

(5) The coating can be adaptable to current spray finishing lines with modifications. (i.e., requires stainless steel hardware).

Guidelines for Market Evaluation:

In working with these companies to investigate possible commercialization of the technology, the laboratory results (as outlined above) were used as the guidelines for making an assessment. Specifically, the guidelines covered both air dry and forced dry finishes for wood.

Air Dry Finishes for Wood

Goal: Develop and commercialize air drying, odorless, no VOC, 'two-in-one' component water-based epoxy systems in which each component is stable (has a shelf life of) at least 6 months.

Application: The mixed material can be applied by brush, roller or single component spray gun yielding applied films, with replicated properties regardless of the time applied after mixing, demonstrating an effective pot life in excess of 8 hours.

Pigmentation: The "A" or Epoxy component can be pigmented to achieve white, inert and normal full color pigments. 'Two-in-one' mixed paints made up of the pigmented "A" components with ADCO selected "B" components yield coatings, (applied by spray, brush or roller), equal to two component solvent-based epoxy maintenance coatings.

Properties: After seven days air dry, the final one mil dry film on unsealed, self-sealed, base coated, or primed wood, has excellent adhesion, flexibility, hardness, water resistance, boiling water resistance, solvent resistance, and stain resistance.

Markets: Coatings with the properties described above have a ready place in the maintenance coatings market including such end uses as protective and decorative coatings for wood furniture, kitchen cabinets, and nitrocellulose replacement coatings.

Force Dry Finishes for Wood

Goal: This is said to be a baking or force dried, odorless, no VOC, 'two-in-one' component water-based epoxy in which each component is stable for at least 6 months.

Application: The mixed material can be applied by brush, roller or single component spray gun yielding applied films, with replicated properties regardless of the time applied after mixing, demonstrating an effective pot life in excess of 8 hours.

Pigmentation: The "A" or Epoxy component can be pigmented to achieve white, inert and normal full color pigments. 'Two-in-one' mixed paints made up of the pigmented "A" components with ADCO selected "B" components yield coatings, (applied by spray, brush or roller), equal to two component solvent based epoxy maintenance coatings.

Properties: After a bake for 10 minutes at 150 degrees F (or equivalent time/temperature combination), the final one mil dry film on wood or regenerated wood products has excellent adhesion, flexibility, hardness, water resistance, boiling water resistance, solvent resistance, flash rust resistance, and salt spray/corrosion resistance.

Markets: Coatings with the properties described above have a ready place in the general industrial and wood coatings market including such end uses as protective and decorative coatings for wood furniture, kitchen cabinets, factory finished wood products, case goods, regenerated wood products, plywood products, and lumber mill and highly automated finishing line wood products.

Product Tests:

ADCO conducted extensive tests prior to submitting substrate samples to each of the five companies. The testing protocol as developed by ADCO laboratory was designed to evaluate the performance and appearance of the newly developed low-VOC wood top coating. The following laboratory tests were conducted:

1. VOC:

The VOC content of the samples was determine to insure the VOC content met the limits of Rule 1136 of 275 g/L. SCAQMD method 304-91 (Determination of Volatile Organic Compounds in Various materials) was used to conduct VOC analysis. ASTM D-1475 was used to determine the density of coatings. Total volatile content was measured by ASTM D-2369. Water content was determined by ASTM D-3792. In regard to any quantifiable substances in the coating pursuant to AB2588, there are no toxic substances or solvents contained in the emulsion.

2. Material and application of Coating:

Solid oak and birch panels of 4-½ x 8 inches were used as substrates of both clear and pigmented coatings. Coatings were applied in a paint booth using Binks High Volume Low Pressure (HVLP) cup gun with a 97 P tip and nozzle with an orifice of 0.070 inches and air pressure at 70 psig. One coating of sealer and one coating of clear topcoat were applied to each substrate. Panels were stored face up for air drying. Evaluation was done after allowing several days for curing.

3. Sanding:

The panels were sanded with 180 grit sandpaper prior to coating. After the sealer was applied and allowed to dry, panels were sanded with 240 grit sandpaper prior to spraying the topcoat.

4. Grain Raising:

Grain raising was minimized by application of a dust coat to seal the pores of the substrate prior to applying the first wet coat.

5. Wet Film Thickness:

It was observed that the wet film thickness (mils) greatly influenced the quality of the finished panels. ADCO applied the top coat to a thickness of between 2-3 mils because it ensured ease of spraying and good flow characteristics. Film thickness of the freshly applied coatings were measured in the wet state following method ASTM D-1212.

6. Dry Times:

Air dry time was defined as the amount of time necessary for the coating to harden before it could be sanded. Also the "dry-to-touch/dry-to-handle" times were measured.

7. Dry Film Thickness:

The dry film thickness (mils) was measured after the top coat was fully cure.

8. Gloss:

ASTM D-523 test was followed using a BYK Tri-gloss meter. Gloss was measured 24 hours after spraying.

9. Blocking:

A laboratory test developed by ADCO blocked the panels at 2 psig. This test was used to evaluate the resistance of a coating to printing under conditions of packaging, shipping and warehousing.

10. Parallel Groove Adhesion:

ASTM test method D-3359 was followed with ratings against five (5) standards ranging from a Gt 0/5B best (i.e., none of the squares of lattice are attached) to a Gt 5/0B worst (i.e., flaking and detachment is greater than 65% of the squares of the lattice.) It was found that surface preparation had a major effect on adhesion.

11. Adhesion/Scrape/Mar:

A modified version of ASTM test method D-2197 was followed only on the substrates. The value given is the weight in grams applied to the stylus before marring is detected. The mean value for the amount of weight which it took to mar the surface of a water-based clear or pigmented coating was 500 grams and 300 grams for solvent based coatings. This method has been found useful in differentiating the degree of hardness of coatings.

12. Orange Peel:

Orange peel is an irregularity in the surface resulting from the inability of wet film to "level out" after being applied. The method described by the instructions for the BYK Wave-Scan were followed. The R scale was used as the measurement which is a relative value based on a scale of 0 to 10.5 (best).

13. Hot/Cold Check:

ASTM test method D-1211 was followed as modified with the Atlas XR-35-A Weatherometer to measure resistance to checking, crazing and cracking of coatings applied to solid oak substrates only when subjected to sudden changes from high to low temperatures. For each test the cycle was repeated 8 times, each cycles taking 3 hours to complete. Relative humidity was maintained at 50%.

14. Household Chemicals:

The methods described in ASTM D-1308 were used. The open spot method of evaluation was used (i.e., the agent was placed directly on the surface and allowed to sit uncovered for 1 hour). Chemicals used were catsup, mustard, coffee, acetone, margarine, vinegar, cold tap water, hot tap water, and nail polish. Ratings were (1) no effect, (2) slight effect, (3) medium effect, and (4) heavy effect.

15. Aesthetics:

A subjective evaluation was made by personnel of the wood coating companies.

Appearance - 10 characteristics (1 is good)

Barrier Coat Compatibility (paper veneer substrate only)

Color - 6 characteristics (1 is good)

Clarity - 2 characteristics good or milky.

V COST/BENEFIT COMPARISON

In order to make a cost/benefit analysis, ADCO submitted selected samples to the Southern California Edison Company Customer Technology Application Center in Los Angeles, California. They has previously undertaken a cooperative study (released in June 1994) for the South Coast Air Quality Management District. The purpose was to evaluate low VOC coatings for Wood Furniture.

This Cooperative study showed several water based clear topcoats met the VOC content requirements of 275 g/l. The performance characteristics of ADCO's new low to no VOC coating were compared with those of other low-VOC water-borne coatings. The physical properties of ADCO's clear finish coating when applied to solid oak compares very favorable with the 25 wood coatings evaluated. Table D-3, D-4, and D-5 showed a comparison of ADCO's wood coating formulation with other topcoat formulations.

(1) Most wood furniture is finished with nitrocellulose, resin-based coatings averaging 750 g/l VOC and 375 g/l hazardous air pollutants (HAPS). For example, in the finishing of an average dining room table (4 ft X 6 ft), about 9 kilograms of VOC's and 4.5 kilograms of HAP's are emitted. While progress has been made to formulate low VOC coating systems, many of these systems use ethylene glycol ethers which are more toxic than most of the solvents used with nitrocellulose. systems. The comparison of the new wood coatings for VOC/toxic compounds with other coatings now on the market is shown in Table D-3.

(2) The new zero-VOC coatings showed excellent performance characteristics in terms of adhesion, dry time, gloss and scrape/mar resistance. The scrape/mar resistance was particularly remarkable (twice as good as the average of other waterborne coatings). The comparison of the new wood coatings for these performance characteristics against other coatings now on the market is shown in Table D-4.

(3) The new zero-VOC coatings showed acceptable chemical and stain resistance.

The resistance to acetone was particularly good in comparison to the other water-borne coatings. The comparison of the new wood coatings for chemical and stain resistance against other coatings now on the market is shown in Table D-5.

In summary, while ADCO's coating showed comparable results in appearance, clarity and appearance, the wood coating appeared to show advantages in three areas:

(1) The finish top coats contain no solvents with a VOC level of <10 g/l. Almost all of the other coatings tested were in the 200-270 range and just barely under the level of 275 per the 7-1-95 SCAQMD Rule 1136 requirement.

(2) Tests of top coats indicated an adhesion/scrape/mar result that was superior to any of the other 25 coatings tested (Table D-4). For ASTM test D-2197, the mean value for water-borne was 500 grams. ADCO's coating was 1050 grams thus indicating a coating that is extremely tough and scratch resistant.

(3) The finish top coating can be competitively priced in the $15-25 per gallon range.

VI PRODUCT/MARKET ASSESSMENT

The following is a company by company market assessment based on laboratory testing and review of the formulation and panels as developed in this contract:

<u>Company A</u>

Company A was supplied with one gallon of ADCO's new two component water borne clear wood coating material along with MSDS and Technical Data Sheets covering the materials.

Test Program:

The Company screening tests included the following:

Substrate - Wood (oak and birch), self sealed, and standard solvent based sealer.

Application Method - Single component spray gun.

Control Standards - Company standard kitchen cabinet solvent-based catalyzed alkyd system, nitrocellulose system, and an experimental proprietary water base system.

Drying Schedule - Varying levels of humidity controlled forced dry.

Test Evaluation - Hardness, mar resistance, stain resistance, solvent resistance, chemical resistance, adhesion, and inter/coat adhesion, and color retention.

Test Results:

The Company's description of the results of the evaluation and prognosis for developing a commercial kitchen cabinet finish generally were positive.

1. Their reported results on hardness, mar resistance, solvent resistance, chemical resistance, adhesion, and color retention were outstanding and extremely encouraging.

2. They identified several areas of concern relating to inter-coat adhesion, short 'pot life', marginal stain resistance, (i.e. not superior to the solvent based alkyd control), and clogging of the air gun used for laboratory application status.

Based upon the positive results to date, Company A signed a "Letter of Intent" to proceed to the next step. They indicated that they would like to focus upon the concerns and two central development aspects focusing on achieving extended 'pot life' and an increase in stain resistance and plan were made to begin further investigation on a joint basis.

However, after due deliberation, Company A indicated that they would not invest in further development/commercialization studies. Such investment would necessarily replace other R & D work. As a matter of management judgement, Company A elected to give preference to other research work since attaining VOC's lower than the SCAQMD Rule 1136 requirements were not top priority.

Company B

Company B was supplied with ADCO's new two component clear water borne clear wood coating material.

Test Program:

The Company screening tests included the following:

Substrate - Wood and steel.

Application Method - Single component spray gun. Immediately place the test panels in variable temperature/humidity drying cabinets (low humidity, medium humidity and over 80% humidity with air temperatures between $40^{o}F$ and $140^{o}F$).

Control Standards - Standard epoxy maintenance coatings.

Test Evaluation - Hardness, toughness, solvent resistance, chemical resistance, and corrosion resistance.

Test Results:

The Company's description of the results of the evaluation and prognosis for developing a commercial product kitchen were positive.

1. Their reported results on hardness, toughness, and solvent resistance were excellent.

2. They identified several areas of concern relating to a marginal to unsatisfactory water resistance and a unacceptable dry rate under conditions of high humidity.

Status:

Company B requested that ADCO resubmit and repeat the program with materials that would have an improved water resistance with faster dry times at higher levels of humidity. ADCO management is considering this request pending the outcome of the evaluation program at the other companies.

Company C

Company C was supplied with ADCO's new two component water-borne clear wood coating material along with MSDS and Technical Data Sheets covering the materials.

Test Program:

The Company's test protocol was termed a feasibility screening evaluation. The screening tests included the following:

Surface - Kitchen cabinet doors; (a) with and without stain (b) self sealed and © with Company sealer.

Application Method - Manual and or suction cup gun spray.

Control - Standard Company kitchen cabinet doors.

Cure and finishing Schedule - Apply self seal, air dry and hot air knife, IR, sand and cure (surface temperature 140^{O}F) Note: They indicated that they were looking for coating that would be "tack free" in something under 2 minutes as opposed to ADCO tests of 15 minutes bake at 50^{O}C.

Test Evaluation - Hot block resistance, hardness, mar resistance, stain and chemical resistance.

Test Results:

The Company's evaluation and prognosis for developing a commercial product were not encouraging. The ADCO clear wood finish did not pass their hot block resistance test. In fairness, they indicated that no other water based product passes their block test. They undertook screening the ADCO material on what they consider to be the really tough test on the basis that if it passed, perhaps further work might be justified. As a result they did not proceed with the other additional planned tests.

Status:

The Company would not invest in further work unless the material passed the block test. ADCO was invited to return if such a material was formulated. Although ADCO could elect to allocate additional resources to address the hot blocking issue in its laboratories, ADCO management has deferred such research pending the outcome of the evaluation programs with the other companies. Company C indicated that based upon the current environmental requirements, there is not a clear need for a no-VOC wood coating.

Company D

Company was D supplied with ADCO's new two component water-borne clear wood coating material along with MSDS and Technical Data Sheets covering the materials.

Test Program:

The Company's feasibility screen evaluation was almost identical to Company C. The screening tests included the following:

Surface - Kitchen cabinet doors; (a) with and without stain (b) self sealed and © with Company sealer.

Application Method - Manual and or suction cup gun spray.

Control - Standard Company kitchen cabinet doors.

Cure and finishing Schedule - Apply self seal, air dry and hot air knife and/or IR, sand and cure (surface temperature $140^{O}F$).

Test Evaluation - Hot block resistance, hardness, mar resistance, stain and chemical resistance.

Test Results:

The Company's evaluation and prognosis for developing a commercial product again were not encouraging. The ADCO clear wood finish did not pass their hot block resistance test. They also undertook screening the ADCO material on what they consider to be the really tough test on the basis that if it passed, perhaps further work might be justified. As a result they did not proceed with the other additional planned tests for hardness, mar resistance, stain and chemical resistance.

Status:

The Company would not invest in further work unless the material passed the block test. Again, ADCO was invited to return if such a material was formulated. Although ADCO could elect to allocate additional resources to address the hot blocking issue in its laboratories, ADCO management has deferred such research pending the outcome of the evaluation programs with the other companies.

Company D also indicated that based upon the current environmental requirements, there is not a clear need for a no VOC wood coating.

Company E

Company E was supplied with ADCO's new two component water-borne clear coating material along with MSDS and Technical Data Sheets covering the materials. The Company currently is not a supplier to the wood industry. Their primary focus is on serving the industrial maintenance coatings market worldwide. Nevertheless, they expressed interest in the basic coating technology and were willing to undertake a testing program.

Test Program:

A feasibility study was undertaken jointly with ADCO for application of the two component water-borne coating material.

Surface - Steel, aluminum and wood.

Application Method - Spray gun.

Control - Standard epoxy maintenance coatings.

Drying - Air dry.

Test Evaluation - Hardness, mar resistance, stain resistance, solvent resistance, chemical resistance, and adhesion.

Test Results:

The Company's description of the results of the evaluation and prognosis for developing commercial coating products were positive. The test results demonstrated excellent air dry clear films for wood, steel and aluminum surfaces.

Status:

Whereas the initial work showed considerable promise, Company E abandoned the project at the time EPA issued VOC guidelines changes allowing epoxy systems with VOC up to approximately 300 grams per liter. In fact the Company put a commercial system into the market some six months later with a VOC of approximately 150 grams per liter. ADCO concluded that the legislation was not tight enough to force the Company into undertaking further research to develop a "Zero" VOC water base epoxy for introduction into the marketplace.

VII SUMMARY AND CONCLUSIONS

Company Conclusions:

The major conclusions for commercialization of such a low-VOC water-borne wood coatings based on the thousands of hours of work done by ADCO alone, and in cooperation with these various companies are as follows:

(1) The chemistry of the ADCO technology is unique and possibly even revolutionary and is patentable,

(2) The finishes obtained showed outstanding performance properties,

(3) The costs of the wood finishes appear to be competitive with current commercial materials,

(4) The coatings as actually developed in the laboratory and subsequently evaluated by these companies will require additional work, (meaning additional investment in laboratory development time), to meet customer end use requirements.

Future Commercial Plans:

Each of the companies basically indicated that the current legislation controlling the solvent emissions allowed VOC's in the range of 250 or possibly even 300 grams per liter plus the manufacturing and marketing costs associated with wood finishing operations would not support their research spending to achieve a "Zero" VOC coating when their competition could continue to sell higher VOC materials.

In addition, each company alluded to the possibility that if "Zero" VOC coating was required for manufacturer or supplier of wood finishes to stay in business, investment in low or no VOC coatings would be required. Since no requirements exist, no further commercialization work would be undertaken.

TABLE D-1. EMISSIONS BENEFIT OF ZERO-VOC WOOD COATINGS FOR KITCHEN CABINET MANUFACTURER

Coating Type	Stain (Low Solid)	Sealer	Topcoat (Clear)	Total
Annual Usage (1000 Liters)	30%	40%	30%	100%
VOC Limits (g/l) 7/1/95 Compliance	480	550	275	-
VOC Emissions (1000 Grams)	144	220	82.5	446.5
VOC Limits (g/l) 7/1/96 Compliance	120	240	275	-
VOC Emissions (1000 Grams)	36	96	82.5	214.5
ADCO/BAT Coatings VOC Content (g/l)	120	-	-	-
VOC Emissions (1000 Grams)	36	-	-	36
Emissions Reduction 7/1/95 Compliance	-	-	-	92%
Emissions Reduction 7/1/96 Compliance	-	-	-	83%

TABLE D-2. EMISSIONS BENEFIT OF ZERO-VOC WOOD COATINGS FOR FURNITURE MANUFACTURER					
Coating Type	Stain (High Solid)	Washcoat	Sealer	Topcoat (Clear)	Total
Annual Usage (1000 Liters)	40%	8%	16%	36%	100%
VOC Limits (g/l) 7/1/95 Compliance	700	480	550	275	-
VOC Emissions (1000 Grams)	280	38.4	88	99	505.4
VOC Limits (g/l) 7/1/96 Compliance	240	120	240	275	-
VOC Emissions (1000 Grams)	96	9.6	38.4	99	243
ADCO/BAT Coatings VOC Content (g/l)	240	120	-	-	-
VOC Emissions (1000 Grams)	96	9.6	-	-	105.6
Emissions Reduction 7/1/95 Compliance	-	-	-	-	79%
Emissions Reduction 7/1/96 Compliance	-	-	-	-	57%

TABLE D-3. VOC/TOXIC COMPOUNDS COMPARISON

MANUFACTURER/ TOPCOAT	VOC (g/l)	AIR TOXIC SUBSTANCES	WEIGHT(%)
ADCO TOPCOAT	<10	NONE	0
AKZO 680-60C018-115 W/B	210	ETHYLENE GLYCOL MONOBUTYL ETHER DIETHYLENE GLYCOL MONOBUTYL ETHER	6.2 3.9
AMT 01TC-0090-50 W/B	240	PROPYLENE GLYCOL N-BUTYL ETHER	1-10
GUARDSMAN 45-1065-40 W/B	270	DIETHYLENE GLYCOL MONOBUTYL ETHER PROPYLENE GLYCOL N-BUTYL ETHER	6.0 3.0
LILLY 787W43 W/B	240	PROPYLENE GLYCOL N-BUTYL ETHER	3.4
PINNACLE 137-CL-1	270	TRIETHYLAMINE ETHYLENE GLYCOL MONOBUTYL ETHER DIETHYLENE GLYCOL MONOBUTYL ETHER	<5.0 3.0 3.0
SHERWIN-WILLIAMS T70C510 W/R	270	ETHYLENE GLYCOL MONOBUTYL ETHER DIETHYLENE GLYCOL MONOBUTYL ETHER	4.8 9.2
SINCLAIR WL 14-9	200	DIETHYLENE GLYCOL MONOBUTYL ETHER	3.0
WATERCOLOR TOPCOAT	100	PROPYLENE GLYCOL N-BUTYL ETHER	1-10

TABLE D-4. PERFORMANCE CHARACTERISTICS COMPARISON				
MANUFACTURER/ TOPCOAT	ADHESION	DRY TIME (MINUTES)	GLOSS 60^{O} SHEEN	SCRAPE/MAR (GRAMS)
ADCO TOPCOAT	GT 0/5B	20-25	80.0	1050
AKZO 680-60C018-115 W/B	GT 0/5B	30-35	34.3	300
AMT 01TC-0090-50 W/B	GT 0/5B	30-35	62.0	500
GUARDSMAN 45-1065-40 W/B	GT 0/5B	30-35	46.8	800
LILLY 787W43 W/B	GT 0/5B	30-35	23.9	300
PINNACLE 137-CL-1	GT 0/5B	30-35	79.4	500
SHERWIN-WILLIAMS T70C510 W/R	GT 0/5B	30-35	44.0	500
SINCLAIR WL 14-9	GT 0/5B	30-35	38.6	400
WATERCOLOR TOPCOAT	GT 0/5B	30-35	37.1	600

TABLE D-5. CHEMICAL AND STAIN RESISTANCE COMPARISON					
MANUFACTURER/ TOPCOAT	ACETONE	COFFEE	MUSTARD	HOT TAP WATER	NAIL POLISH REMOVER
ADCO TOPCOAT	1	1	2	1	2
AKZO 680-60C018-115 W/B	3	1	2	1	2
AMT 01TC-0090-50 W/B	2	1	2	1	2
GUARDSMAN 45-1065-40 W/B	2	1	2	1	3
LILLY 787W43 W/B	2	1	2	2	3
PINNACLE 137-CL-1	2	1	2	1	1
SHERWIN-WILLIAMS T70C510 W/R	2	1	2	1	2
SINCLAIR WL 14-9	2	1	2	1	2
WATERCOLOR TOPCOAT	1	1	1	1	2

LEGEND:
1. NO EFFECT
2. SLIGHT EFFECT
3. MEDIUM EFFECT
4. HEAVY

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completi

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16. ABSTRACT The paper discusses a project, cofunded by the South Coast Air Quality Management District (CSAQMD) and the U. S. EPA, to develop a new low volatile organic compound (VOC) wood coating. Traditional wood furniture coating technologies contain organic solvents which become air pollutants as the coating cures; mitigation by add-on control devices would be energy intensive. Air emissions can be reduced through the pollution prevention approach of shifting to low-VOC coatings, avoiding the energy penalty. This project evaluated a new low-VOC wood coating technology (a two-component water-based epoxy) by determining its performance characteristics, conducting application and emissions testing, and assessing the cost benefits for energy conservation and air pollution reduction. The composition of the basic epoxy polymer was varied in combination with several curing agents. The resulting top coat was as good as, or better than, other low-VOC waterborne wood furniture top coats for adhesion, gloss value, dry time, hardness, level of solvents, and chemical and stain resistance. The VOC content of the clear and the white pigmented top coats was less than 10 g/L. The cost of this low-VOC wood coating is comparable to that of other low-VOC coatings. Improved dry times were identified as being critical for product improvement. A marketing plan was developed.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Solvents	Pollution Prevention	13B	11K
Epoxy Coatings	Curing	Stationary Sources	11C	13H
Wood		Volatile Organic Compounds (VOCs)	11L	
Organic Compounds			07C	
Volatility			20M	
Furniture			15E	

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