New High Performance Two-Component Wood Coatings Comprised of a Hydroxy Functional Acrylic Emulsion and a Water-Dispersible Polyisocyanate

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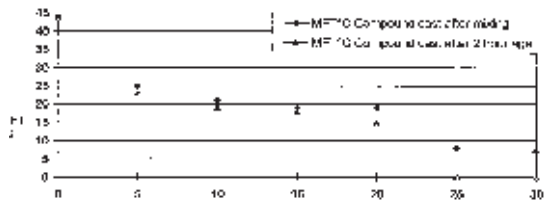
Statistical methods were used to develop hydroxy functional acrylic emulsions for use with a water-dispersible polyisocyanate crosslinker. The resulting two-component waterborne coating systems were optimized for kitchen cabinet and office furniture applications. Key performance criteria included appearance and aesthetics, pot life, print and mar resistance, and chemical resistance involving both Kitchen Cabinet Manufacturers' Association (KCMA) and office furniture requirements. Statistical analysis revealed several strong correlations between acrylic emulsion hydroxy level, particle size, composition T_g, polymerization process and wood coating performance. For example, smaller acrylic emulsion particle size was found to yield many performance benefits with few detriments.

Coating formulation variables were also found to be significant. Ultimate coating hardness increased with water-dispersible polyisocyanate level, yet early hardness readings correlated negatively with water-dispersible polyisocyanate level. Plasticization and crosslinking effects were thought to be responsible. A higher ethylene glycol monbutyl ether (EB) coalescent level was found to correlate negatively with coating hardness, suggesting a reaction between the EB hydroxyl group and the water-dispersible polyisocyanate, resulting in plasticization of the coating.

BACKGROUND

Two-component (2K) waterborne polyurethane coatings have become increasingly popular over the last several years, driven by market demands for higher-performance, formaldehyde free, thermosetting water-based coatings. Water-dispersible polyisocyanates (WDPI) have been specifically developed for use in such coatings as crosslinkers in conjunction with hydroxy-functional polyols (acrylics, polyester or polyurethane dispersions).[1-3] The main reaction in 2K polyurethane coating systems is the condensation between WDPI isocyanate (NCO) groups and the polyol hydroxy (OH) groups (*Scheme* 1, Path 1). NCO can also react with water at ambient temperatures, forming urea groups and releasing carbon dioxide (*Scheme* 1, Path 2). In an aqueous system, this water reaction must be minimized. The WDPI used in this study is an aliphatic polyisocyanate that reacts with water slowly.[1] In addition, hydrophilic modification contained in this WDPI enables formation of stable dispersions in water. It is theorized that a polyurea skin may form around the dispersed WDPI particles reducing water entry, thus slowing further NCO/water reaction. These features allow the development of 2K coating systems with a practical pot life of several hours.



Scheme 1

Resin choices for clear wood coatings have expanded in recent years. Thermoplastic and self-crosslinking (1K)

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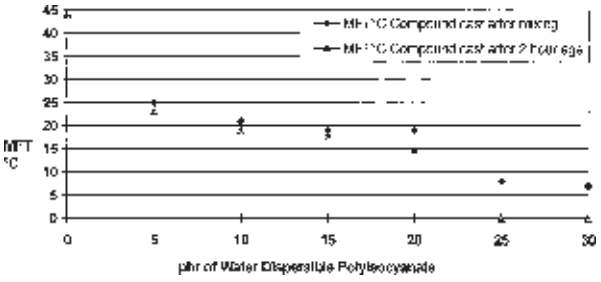

Figure 1—Level of WPDI versus formulation MFT.

acrylic emulsions have been developed for various wood coating applications including kitchen cabinets, and, in combination with urethane dispersions, contractor, and DIY floor and general purpose coatings. Though these emulsions are commercially employed, it may be difficult to economically achieve the high crosslink densities required to create coatings fully resistant to aggressive solvents and cleaners with such 1K approaches. The use of WDPIs with hydroxy functional acrylic emulsions (HFAEs) in a 2K coating creates potential for high crosslink density due to multiple NCO and OH crosslinking sites in single molecules of the WDPI and HFAE, respectively. High NCO/OH co-reactivity, combined with retarded WDPI water reactivity, make high crosslink density coatings possible even under low temperature curing conditions (100-140°F) commonly used by wood finishers.

Traditional 2K solvent polyurethane coatings employ relatively low molecular weight (MW) polyols and polyisocyanates. Component MW is limited by solution viscosity at practical solvent contents. Molar proportions of NCO to OH groups are typically expressed as an "NCO/OH" ratio. In such solvent systems, NCO/OH ratios of approximately one or slightly higher are often preferred. The use of an aqueous acrylic emulsion overcomes one solvent chemistry restriction: emulsion viscosity is largely independent of MW. Furthermore, a higher MW polyacrylate building block is expected to offer greater performance robustness with regard to NCO/OH stoichiometry. For example, an acrylic polymer chain with an MW on the order of a million, having perhaps hundreds of hydroxyl groups in a single molecule, may not require reaction of all OH groups (i.e., NCO/OH=1) to develop substantial crosslinking. In fact, relatively few condensations may move the system towards a crosslinked network. Thus, unlike traditional solvent systems, the WDPI can be viewed more as a crosslinker rather than a co-reactant, much as polyaziridine and melamine are crosslinkers for acrylic emulsions.

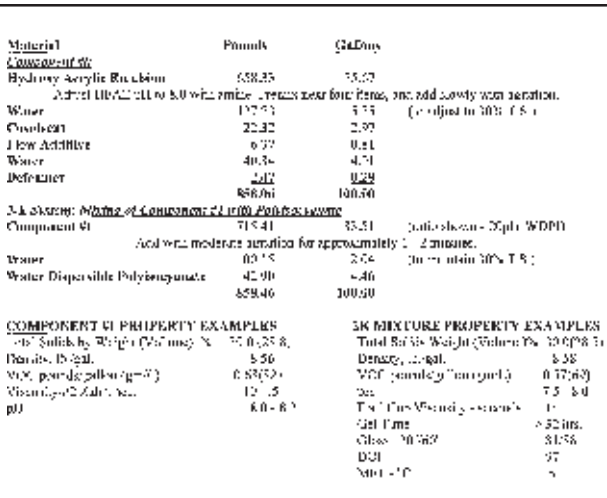

Figure 2—Basic test formulation.

Acrylic emulsions are employed in a very broad range of applications among a diverse set of markets. Product characteristics, for example, hardness, flexibility, chemical resistance, abrasion resistance, etc., differ enormously according to application demands. Both monomeric and auxiliary components used in the polymer and polymerization process strongly influence acrylic emulsion and application properties. Formulation ingredients, such as additives, solvents, neutralizing agents, etc., also have major effects. Given the diversity of acrylic emulsion characteristics, we chose a thermoplastic acrylic wood coating as a general starting point for this study. We felt that 2K WDPI crosslinked coatings might benefit from the already good performance of the thermoplastic system selected. We expected that through suitable redesign, together with the study of polymer and formulating variable impact on final coating properties, we could create an improved HFAE for development of 2K WDPI crosslinked coatings with performance superior to that of current commercial coatings.

OBJECTIVE

Our goal was to investigate key variables in both acrylic emulsion synthesis and coating formulation that were expected to influence 2K waterborne WDPI/HFAE coating performance, and subsequently optimize these variables to create a coating system for kitchen cabinet and office furniture markets. We targeted performance superior to current commercially available systems.

APPROACH

Seven HFAE polymerization and coating formulation variables were jointly identified as potentially having significant performance impact against KCMA and office furniture requirements. Experimental design methods were chosen to develop a study of these variables and selected interactive effects, to understand their correlations to coating performance, and to enable optimization towards superior performance. The independent variable choices are as follows:

HFAE Polymerization Variables

Hydroxyl Level: Because the crosslinking reaction involves NCO and OH groups, the level of OH groups was expected to influence the extent of crosslinking. The

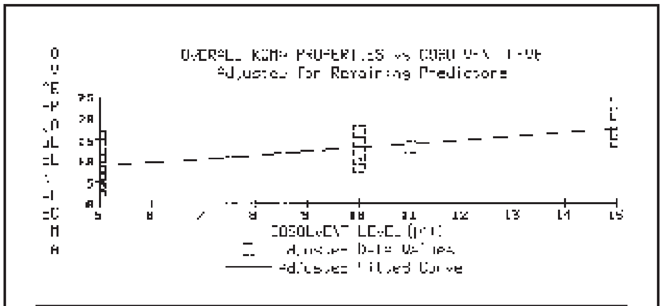

Figure 3—Sum of KCMA properties versus coalescent level.

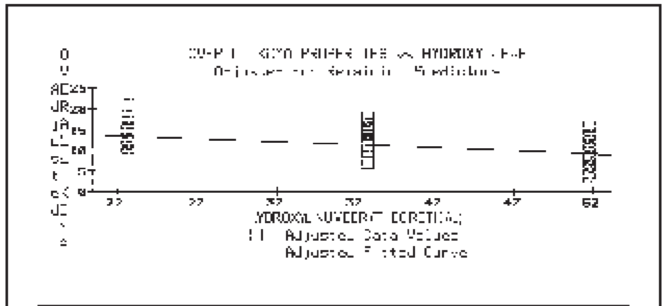

Figure 4—Sum of KCMA properties versus HFAE hydroxy level.

monomers and other components of the HFAE that yield OH groups were kept the same for this study.

Polymerization Process: Even for polymers having identical compositions, emulsion polymer "particle architecture" can significantly change coating performance. Two polymerization processes were selected to provide emulsions differing in composition distribution, functional group placement, and particle morphology, all components of "particle architecture."

Composition T_g: Crosslinked coatings have different hardness and flexibility characteristics than thermoplastic coatings. Furthermore, WDPIs can aid HFAE film coalescence, making harder coatings with lower volatile organic compounds (VOCs) possible. Complicating this picture, good HFAE/WDPI interdiffusion is needed. If crosslinking begins before interdiffusion, as with a polymer that becomes glassy too quickly, then "surface crosslinking" could occur, limiting further interdiffusion and resulting in a significant uncrosslinked polymer. We decided to look at HFAE T_g in light of these issues. Composition T_gs were estimated using a linear empirical model that has shown reasonable predictability in our past experience. Monomer weight ratios and estimated monomer homopolymer T_gs were inputs into the model.

Acrylic Emulsion Particle Size: Smaller emulsion particle size might increase the WDPI access to polymer chains within HFAE particle interiors. Furthermore, acrylic emulsion particles are thought to play a role in dispersing the WDPI, and in the morphology of the combined dispersion.[4,5] Particle size was measured for each HFAE in this study. We adjusted particle size to approximate experimental design high and low targets with small HFAE formulation changes. While HFAE particle size is truly not an independent variable, we would expect performance consequences of the small formulation changes separately from their effect on particle size to be very minor.

Coating Formulation Variables

Level of WDPI: Rather than using a conventional NCO/OH stoichiometric ratio, we decided to define the WDPI level in absolute weight percent (phr) for the following reasons: (1) the formation of a highly crosslinked network in these systems may not require full reaction of HFAE OH groups (see previous discussions in this paper); (2) absolute WDPI levels simplify the statistical analysis involved; and (3) HFAE OH level is a theoretical value. The "true" OH number will depend on the accessibility of OH groups.

Neutralizing Amine: The amine used to neutralize HFAE formulation pH to 8.0 can also react with the WDPI. We chose to investigate a less reactive tertiary amine, DMEA (dimethylethanolamine), as well as the more commonly used ammonium hydroxide.

Agitation During the Dispersion of the WDPI in the HFAE: Controlled dispersion of the WDPI into small droplets is necessary to achieve good crosslinking and appearance properties.[4,5] During initial work in this study, we found the mixing effects on performance to be so strong that we decided to fix the mixing level. This allowed us to more clearly separate the effects of the other variables in this study.

Coalescent Level: We initially chose ethylene glycol monobutyl ether (EB) as a broadly compatible and effective coalescent for this study. Neat HFAE minimum film forming temperature (MFT) screening work showed a need to vary EB level to achieve good film formation.

Table 1—Dependent Variable Settings and Basic Test Results

Reference	Emulsion Variables					Formulation Variables			MFT Results			Appearance Results (1-5 scale)					
Exp #	HFAE #	OH #	Process	Comp Tg °C	Part. Size nm	Amine Type	Coal Lvl phr	WDPI Lvl phr	HFAE °C	Formula °C	Dry Time min	Craw Cont	Sparkle	Gloss	DOI	Gel Time hrs	Ford Cup sec
1	-21	32.6	A	27	[illegible]	AMM	5	0	24	<5	15/16	4	3	62/78	64	>48	3
2	-21	32.6	A	25	[illegible]	AMM	5	40	[illegible]	<5	5.5/15	4	4	60/80	70	[illegible]	4
3	-32	22.6	A	53	97	DMEA	7	30	43	2	15.5/17	4	5	28/45	34	19	12
4	-32	22.6	A	53	97	AMM	11	30	43	<2	16.5/17	5	4	45/72	80	>48	12
5	-32	22.6	A	53	97	AMM	11	15	43	<2	16/16.5	1	3	60/74	52	19	12
6	-26	22.6	B	50	68	DMEA	15	20	41	<5	20/20.5	1	6	22/30	2	24	23
7	-26	22.6	B	50	68	DMEA	15	20	41	<5	11/12	1	5	57/70	70	>48	23
8	-26	22.6	B	50	68	AMM	15	20	41	<5	21/21.5	1	6			>48	23
9	-26	22.6	B	50	68	AMM	15	20	41	<5	20.5/21	1	4	40/50	95	24	22
10	15	22.6	B	22	105	AMM	5	40	15	6	12/12.5	1	2	58/65	58	19	3
11	15	22.6	B	22	105	DMEA	5	0	15	4	[illegible]	1	2	58/65	50	>48	2
12	15	22.6	B	22	105	DMEA	5	5	15	3	12/12.5	1	1	30/40	95	>48	3
13	-25	37.3	A	53	[illegible]	DMEA	5	0	39	[illegible]	13/13.5	2	1	58/51	78	>48	12
14	25	37.2	A	53	79	AMM	5	40	39	6	12.5/13	3	1	21/54	64	19	2
15	25	37.4	A	53	71	DMEA	5	40	39	6	12/14.5	1	2	67/54	84	19	2
16	-32	37.8	A	25	98	DMEA	5	10	27	<5	11/11.5	1	1	44/51	80	>48	13
17	32	37.8	A	25	98	DMEA	5	40	27	<5	5/14.5	1	1	67/52	50	18	2
18	32	37.8	A	25	96	AMM	5	40	27	<5	5/5	1	1	42/51	84	18	1
19	-23	51.5	A	25	84	DMEA	5	10	6	<5	10.5/11.5	2	2	20/54	77	>48	15
20	-23	51.5	A	25	84	AMM	5	40	6	<5	15/17	2	1	75/55	62	18	13
21	23	51.5	A	25	84	DMEA	5	5	6	<5	11/12	2	2	65/54	65	>48	14
22	-31	51.6	A	53	95	AMM	5	30	37	1	14.5/15	1	1	52/75	68	18	12
23	-31	51.6	A	51	95	AMM	11	10	37	<2	13/14.5	3	3	29/37	47	>32	12
24	-31	51.5	A	53	95	DMEA	11	15	37	<2	14/14.5	4	3	40/74	41	>32	12
25	-31	51.5	A	53	95	DMEA	19	10	37	12	14.5/15	3	3	60/79	49	>32	13
26	-29	51.6	B	33	72	DMEA	5	20	26	5	12/12.5	2	3	81/90	97	>32	17
27	-29	51.6	B	33	72	AMM	5	10	26	6	12/12.5	3/4	1	79/87	27	>32	17
28	-29	51.6	B	33	72	DMEA	5	20	26	<5	11/11.5	1	1	82/88	96	>32	12
29	-30	51.6	B	53	103	DMEA	10	10	42	17	12/12.5	1	1	75/55	96	>32	13
30	-30	51.6	B	53	103	AMM	10	20	42	6.5	14.5/15.5	6	6	32/48	11	>32	12
31	-30	51.6	B	53	103	AMM	10	10	42	12	11/11.5	2	1	77/88	95	>32	11

* Cracked

However, MFT of the 2K coating system was also influenced by the coalescing effect of the WDPI on the HFAE. *Figure* 1 shows this effect on one HFAE studied. We premeasured MFT for each formulated 2K coating. EB level was then optimized to ensure good film formation. The basic test formulation developed for this work is shown in *Figure* 2. *Table* 1 shows EB level and MFT for all coatings studied.

EXPERIMENTAL

Materials

WDPI used in this study was an aliphatic polyisocyanate, hydrophilically modified for better dispersibility in water. Its characteristics are as follows:

Solid Content (wt%) 100
NCO Content (wt%) 17.1
Equivalent Weight, (as supplied) 245
Viscosity, cP 1000-5000

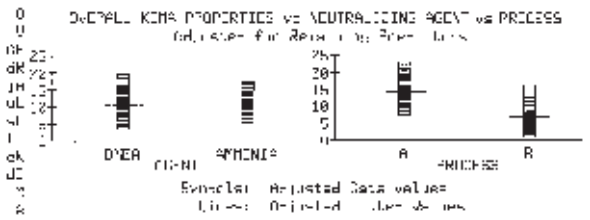

Figure 5—KCMA sum versus neutralizing amine type and polymerization process.

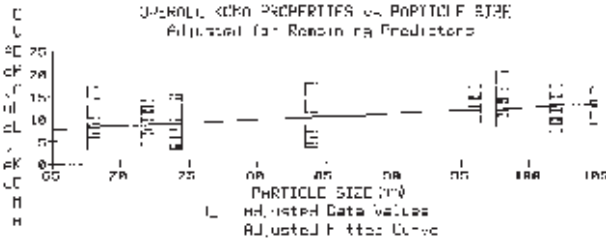

Figure 6—Sum of KCMA properties versus HFAE particle size.

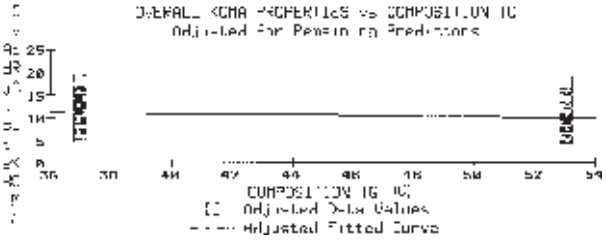

Figure 7—Sum of KCMA properties versus HFAE composition T_g.

HFAEs used in this study have the following characteristics:

Solid Content (wt%) 40-41.5%
Other Properties ..... See *Table* 1

Evaluation

Coating evaluation was broken down into three categories:

- Basic tests: dry time (sand and hard dry), appearance, pendulum hardness, gel time, viscosity, MFT, gloss, and distinctness of image (DOI). (Detailed in *Appendix* A).
- KCMA tests: Chemical resistance tests (KCMA Standard, section 9.3)[6]
- Office furniture tests: Detailed procedures are included in *Appendix* B.

Additional tests were conducted on one of the optimized systems: hot water spot test, hot and cold cycle check, solvent entrapment, nickel scratching, and early printing resistance. The procedures for these tests are given in *Appendix* C. Test results are shown in *Table* 5.

RESULTS AND DISCUSSION

Experiments were developed using a D-optimal experimental design approach. This allowed estimation of the independent HFAE and formulation variable main effects as well as selected quadratic and HFAE/formulation interactive effects. The design originally contained eight independent variables, four HFAE variables, and four formulation variables. After work was started, the design was complicated by our decision to remove agitation as a variable and replace it with coalescent level. Fortunately, enough degrees of freedom were available so as not to significantly confound the effects of the independent variables. *Table* 1 shows the independent variable settings for this design, along with basic test results.

The statistical analysis of our data revealed several significant correlations between independent HFAE polymer variables and coating formulation variables, and the dependent wood coating properties. *Figures* 3 to 8 show one set of analyses around an overall summation of KCMA performance ratings (lower numbers are best). Similar individual analyses were conducted for each KCMA and office furniture performance property. *Table* 2 summarizes selected performance correlations that resulted from these analyses, all at 95% or greater confidence levels. Key findings include:

Formulation Gel Time: A concern with 2K coatings is their tendency to build viscosity and eventually gel upon aging. We found higher WDPI level correlates strongly with shorter formulation gel time. Higher HFAE hydroxy level, however, gave increased gel time. Many of the coating systems studied, including those made with the HFAEs we eventually optimized, never did build viscosity nor gel. While lack of viscosity build provides a significant advantage, it does not imply extended pot life. After dispersion, WDPI NCO functionality is lost over a period of several hours to water reactions. Our

Table 2 : Selected Performance Conclusions

Response (To Improve)	HFAE Variables: Hydroxy Level	Particle Size	Process	Composition Tg	Formulation Variables: WDPI Level	Amine	Coales. Level
Increased Initial Hardness	L +	L	D +	H + +	L +	Amm —	L ++ (C)
Increased 2hr Hardness	L +	L +	D +	H +	L +	Amm	L ++ (C)
Increased 7 day hardness	o	L ++	B +	H	H	o	L + (C)
Gel Time	H—	o	B —	o	L ++	DMEA +	o
Draw Down Appearance	o (C)	L ++	o	o	o (C)	o	H ++
Spray Appearance	H +	o	o	L +	o	Amm +	o
20 degree gloss	M-H + (C)	L +	B	L ++	M + (C)	Amm	M + (C)
60 degree gloss	M-H — (C)	L —	B —	L ++	M — (C)	Amm	L-M (C)
Draw Down DOI	M-H (C)	o	o	o	o	o	L-M + (C)
Water Soak	H +	L	A	L +	H +	DMEA +	H +—
Ethanol Resistance	H +	o	o	o	o	o	L +
Lipstick Resistance	H +	o	B +	o	o	o	o
Mineral Spirits Resistance	o	L +—	o	L ++	o	o	o
Nail Polish Remover	H ++—	o	o	L ++	H ++—	o	H ++—
Tap Water Resistance	H +	H +	o	o	L +	o	L ++
Mustard Resistance	H +	o	D	o	o	o	o
Olive Oil Resistance	H +	L +	D	o	H +	DMEA	H +
Overall KCMA Stains	H +	L +	B +	o	H +	o	L
Overall DOE Stains	o	o	o	o	H +—	DMEA +	L
Best Overall Properties	H	L	D	?	H	?	M /
Optimized HFAE settings	H	L	H	L	N/A	N/A	N/A

Key : L=Low, H=High, M=Middle Level, C=curvature, I=significant interactions
++ = strongly positive, + = slightly positive, o = no significant interaction

findings simply show that it is possible to avoid viscosity build under these conditions.

WDPI Level Effect on Hardness with Dry Time: Increasing the WDPI level was shown to soften the coating after initial drying and after two hours of ambient aging. However, after seven days, higher WDPI level increased film hardness. Knowing the plasticization effects of the WDPI on the HFAE, these findings confirmed that crosslinking occurred gradually over hours or days. With time, hardening results from crosslinking and from decreasing plasticization as WDPI is consumed. *Figure* 9, showing overlaid transmission IR spectra of one coating at different ambient cure times, supports our theory. The spectra show a gradual NCO decrease at coating cure times of 2, 4, and 29 hr. Most of the NCO functionality is consumed after 58 hr (2 $^1/_2$ days).

Coating Hardness/Appearance: Our analysis showed conflicting coating hardness and appearance effects. Increasing HFAE composition T_g increased coating hardness at all cure times, but was detrimental to spray appearance and gloss. We also found that EB coalescent level must be minimized for maximum hardness. While residual coalescent softening is expected for early hardness results, it was surprising that higher EB reduced seven-day hardness. We would expect the coating to be free of EB after seven days, based on our experience with other EB coalesced coatings. One possibility is that the hydroxy group in the EB molecule is reacting with the WDPI, building plasticization into the crosslinked coating. We are currently investigating alternative coalescents.

Acrylic Emulsion Hydroxy Level Effects: We found that higher HFAE OH functionality had several benefits, particularly in coating appearance and resistance properties, with few detrimental effects. These effects could be separated from the WDPI level, in other words, higher OH level gave many positives at both high and low WDPI level. We have two possible explanations for these findings. The OH groups may not all be accessible due to their locations within the HFAE particles. Higher OH levels may increase crosslinking efficiency either through greater OH availability, or perhaps through improved compatibility of the WDPI and acrylic phases.

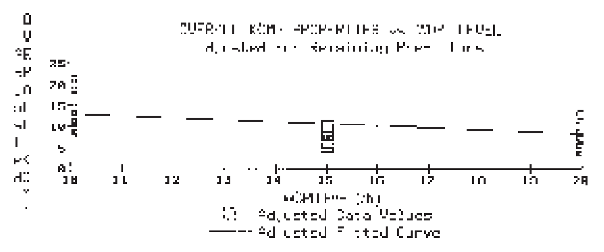

Figure 8—Sum of KCMA properties versus formulation WDPI level.

Acrylic Emulsion Particle Size: Our results showed smaller HFAE particle size to have many performance benefits with few detriments. Appearance and hardness properties were most benefited. We believe smaller HFAE particle size may improve OH accessibility either through increased particle surface area or shorter diffusion paths into particle interiors. We also know capillary forces during film formation increase as particle size decreases.[7] These forces may help coalesce the WDPI and HFAE phases. Improved WDPI dispersion is also possible with a smaller particle size HFAE.

Acrylic Emulsion Process: Given equivalent HFAE composition and particle size, process "B" was found to be advantageous in coating hardness and in overall KCMA performance. The A and B processes were selected to provide differences in the "particle architecture" of the HFAE. The results confirm that particle architecture is an important HFAE consideration. More fundamentally, WDPI and HFAW miscibility and interdiffusion and coating film formation, all of which might be influenced by particle architecture, need to be considered in HFAE design.

Type of Neutralizing Amine: We saw no clear advantage in DMEA over ammonium hydroxide, despite the expected differences in WDPI reactivity of these amines.

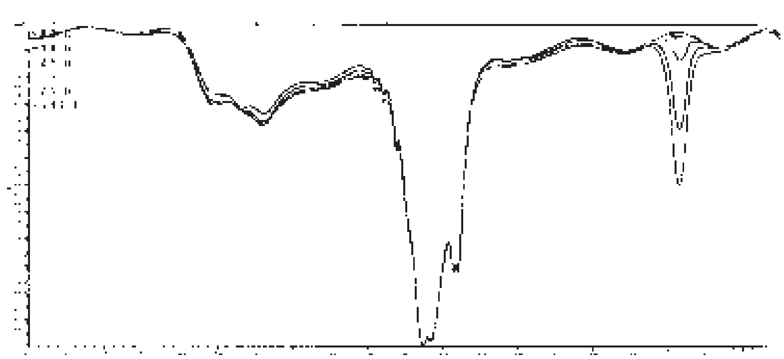

Figure 9—Transmission IR spectrum–Isocyanate decrease with ambient cure time.

Table 3: KCMA Results: Commercial Systems vs. Alternate Technologies

Reagents	Optimized HFAE #1	Optimized HFAE #2	Competitive HFAE	Nitro-Cellulose Lacquer	Acid Catalyzed
Vinegar	0	0	0	0	0
Tomato Juice	0	0	0	0	0
Orange Juice	0	0	0	0	0
Grape Juice	0	0	0	0	0
Ketchup	0	0	0	0	0
Coffee	0	0	0	0	0
Olive Oil	0	0	0	0	0
100 Proof Alcohol	0	0	0	0	0
Formula 409	0	0	0	0	0
Mustard	0	0	2	1	2
Edge Soak	1	1	5	5	5
Total Sum	1	1	5	7	5

(0=No Effect, 1=Very to Slight, 2=Slight, 3=Slight to Moderate, 4=Moderate, 5=Moderate to Heavy, 6=Heavy)

Table 4: Office Furniture Results: Commercial Systems vs. Alternate Technologies

	Optimized HFAE #1	Optimized HFAE #2	Competitive Emulsion	NC Lacquer	Acid Catalyzed
Tap Water	0	0	0	0	0
Coffee	0	0	0	1	0
1% Dawn	0	0	0	0	0
Red Oil	0	0	0	0	1
Mineral Spirits	0	0	0	0	0
50/50 Ethanol	0	0	0	6	3
Mustard	0.5	0.5	0.5	0	1
Acetone	0	0	0	6	6
Nail Polish Remover	0	0	1	6	6
Amyl Acetate	0	0	1	6	6
Coty 24+ Lipstick	2	1	3	1	1
Mustard	4	4	6	6	6
Tomato Juice	0	0	0	0	0
Grape Juice	0	0	0	0	0
Coca-Cola	0	0	0	1	0
Blue Ball Pen	0.5	0.5	1	1	1
Liquid Corrector	2	2	3	0	0
Total Sum	9	11	15.5	30	25

Though DMEA is expected to be slower reacting due to the tertiary amine functionality, it is also slower evaporating during film coalescence. It is possible that the WDPI loss due to side reaction with amine is not significant at such a low amine level.

Coalescent Level: We were surprised to find the level of coalescent to have such strong effects on several properties. Our findings supported careful optimization of coalescent level to the minimum needed to achieve good appearance properties. We believe that non-hydroxy functional coalescents need to be investigated in these systems.

Based on these findings, we developed two similar optimized acrylic emulsions, and compared them to three commercially employed wood coating technologies.

Optimized HFAE Parameters:
- Hydroxy level—high—OH# = 52
- Particle size—small
- Polymerization process—B
- Composition T_g—low (MFT ~25°C)

Comparison—Optimized Systems Versus Commercial Technologies: We compared the two optimized HFAE/WDPI coatings to representative water-based (W/B) and solvent-based (S/B) systems currently used in the market place: an S/B nitrocellulose lacquer, an S/B acid catalyzed varnish, and a W/B HFAE/WDPI system. *Table* 3 shows KCMA testing comparisons, and *Table* 4 shows office furniture data. *Table* 5 shows additional test results conducted on a coating using optimized HFAE#2.

In *Table* 3, we see excellent KCMA performance for the optimized coatings in all test parameters. Although most of the coatings showed some mustard staining, all stains faded to "pass" in the requisite time. Only the newly developed HFAE#1 and HFAE#2 coatings passed the edge soak test with "1" ratings, while the commercial coatings failed with ratings of 3 to 6. *Table* 4 data shows the outstanding performance versus office furniture requirements that is possible with the new systems. As evidenced by the final sum ratings in this table, the coatings utilizing HFAE#1 and HFAE#2 significantly outperform the commercial controls. The additional test data in *Table* 5 also show our coating based on HFAE#2 to have excellent cold check, early print resistance, and nickel scratch resistance.

Overall, the application and performance properties of the optimized coatings we developed exceeded those of commercial standards in both KCMA and office furniture tests. We also observed advantages in ease of application and appearance properties over current coatings. Inherently, the optimized HFAE/WDPI coatings offer advantages in lack of formaldehyde release and low VOCs as well.

Table 5—Additional Test Results Using Optimized HFAE#2 and WDPI

Test	Results
Hot Water spot test	Pass
Cold check	Pass 20 cycles
Solvent entrapment	Pass
Nickel scratch test	Pass at 5kg
Early printing resistance	Slight to none

CONCLUSIONS

In our study, strong correlations between coating performance characteristics and several hydroxy functional acrylic emulsion (HFAE) and formulation variables were found. Key performance drivers in the design of the HFAE include hydroxy level, emulsion particle size, polymerization process, and composition T_g. Key formulation variables include the water-dispersible polyisocyanate (WDPI) level and coalescent level. We also found indications that coalescent type may be critical.

Two coating systems based on optimized HFAEs combined with a commercial WDPI were developed from the results of this statistical study. Our data shows that these optimized two-component coatings show outstanding wood coating performance properties. The new coatings developed offer aesthetic advantages and lack of viscosity build with time. Overall performance surpassed current commercial benchmark systems in both KCMA and office furniture testing.

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Appendix A: Basic Test Procedures

Drying Time: ASTM D 1640-83.

Pendulum Hardness: Films (WFT=3 mil) were drawn down on a clean glass plate. Koenig pendulum hardness was measured at a given time period after hard dry time.

Viscosity: Formulated paint viscosities were measured at ambient temperature immediately after mixing using a #4 Ford cup.

Gloss and DOI: Films were formed by spray out on to a black glass panel using a conventional spray gun (atomizing pressure: 35 psi). After a 24-hr aging period, gloss was measured on a BYK-Chemie gloss unit and DOI on a Dorigon II DOI meter.

Appearance: Assessed visually for flow and leveling, amount of microfoam, presence of any major defects, with 0 being best and 6 being worst.

Gel Time: Assessed visually. Reported times represent how long formulated paint had remained free of any sign of gelation.

Appendix B: Chemical Resistance Test Procedures

Wood Panel Preparation: Presanded and stained wood panels were coated with a sealer and a topcoat (WFT=3 mil) with light sanding (320 grit stearated paper) carried out between. Panels were flashed 15 min at the ambient temperature then baked 15 min at 140°F. Tests were conducted on the finished panels 14 days after the finish.

KCMA Standard Chemical Resistance Tests[6]: With the testing panel in vertical position, place about 3 mL of each of the following tests materials on the surface and let stand for 24 hr (except mustard for one hour): vinegar, lemon, orange and grape juices, catsup, coffee (prepared with one teaspoon of instant coffee per cup of hot water at 115°F), olive oil, 100-proof alcohol, 0.5% (wt) liquid dishwashing detergent solution, mustard. Sponge-wash the surface with clean water and a clean cloth before evaluation. Visual readings were carried out, with 0 being no effect and 6 being the worst effect. A reading of 2.5 is the minimal requirement for pass.

KCMA Edge-Soak Test[6]: Prepare 0.5% wt liquid dishwashing detergent solution and fill a trough with a #8 sponge to 0.5 inch below the top level of the sponge. Place test door vertically on the sponge and let stand for 24 hr. The same procedure of cleaning and evaluation as in KCMA standard tests applies here.

Office Furniture Spot Test: Reagents (1 mL on a cotton ball if liquid) were placed on panel surfaces and covered with a watch glass for 16 hours before evaluation. Visual readings were carried out, with 0 being no effect and 6 being the worst effect. A reading of 2.5 is the minimal requirement for pass.

Appendix C: Test Procedures for Additional Tests

Hot Water Spot Test: Presanded and stained wood panels were prepared half coated with sealer only and the other half coated with sealer and topcoat. Immediately after finish, while the panel was still hot out of the oven, a 1 mL tap water (on a cotton ball) was placed over the sealer and two-coat portion of the panel, respectively, and covered with a watch glass. Effects on the coating were checked 1 hr and 24 hr later.

Hot and Cold Cycle Check: The test panels were placed in a Thermotran and the cycles were set as follows: 1 hr at 49°C, cool down to 21°C within 15 min, stay at 21°C for 15 min, cool down to –21°C within 15 min, stay at –21°C for one hour, ramp back to 49°C with the same schedule as it was cooling down. Twenty cycles completed before evaluation.

Solvent Entrapment: Presanded and stained wood panels were finished with one coat of sealer and one coat of topcoat as described previously. After 14 days of aging, panels were placed in an oven at 90°C for 16 hr and checked for effect.

Nickel Scratch Test: Finished and aged (14 days) wood panels were placed under a modified balanced beam scrape adhesion and mar tester with a nickel replacing the loop stylus. Maximum weights (kg) were recorded under which the coating, upon scraping the nickel across the surface, showed no sign of break through.

Early Printing Test: Presanded and stained wood panels were finished with one coat as a sealer and one coat as a topcoat as previously described. Immediately after finishing and cooling, four-pound weights were placed on pieces of duck cloth over each of the panels. The weights and panels were then placed in a 125°F oven for one hour. The weights and duck cloths were removed and any "printing" on panel surfaces was evaluated.