

## Reactive Copromoter for Unsaturated Polyester Resins

by  
Jeffery E. Powell and Angela H. Honeycutt  
Eastman Chemical Company  
P.O. Box 1974, Kingsport  
TN 37662-5230

## Reactive Copromoter for Unsaturated Polyester Resins

Ambient temperature cure unsaturated polyester resins provide the ability to produce high-quality, value added composite products. To initiate cure, these thermoset resin systems require free-radical sources, with the most common being methyl ethyl ketone peroxide (MEKP), and a cobalt salt generally known as the promoter. Copromoters are used to further accelerate cure by interaction with the cobalt salt making it more effective at decomposing the organic peroxide. Some copromoters can be water soluble; thus, their use levels must be balanced with the effect on moisture resistance since they do not crosslink into the polymer matrix. Reactive copromoters provide the ability to achieve faster cure and cure into the polymer matrix. Additionally, some reactive copromoters can serve a dual purpose by reducing the usage of styrene. This can be especially important when formulations need a few percent less styrene to achieve MACT compliance. This paper explores the use of a reactive copromoter in typical unsaturated polyester formulations.

### Introduction

Unsaturated polyester resins (UPR) were first commercially developed in the 1940's and have grown to be one of the most versatile, globally used, thermoset polymer systems. This versatility allows manufacturing of many useful products common in modern society.

Unsaturated polyester resins cure by a free-radical mechanism. The high free-radical flux needed to cure the thermoset resins can be generated under many conditions: room temperature, heat, UV light, or visible light, provided the appropriate free-radical initiator is used. Room temperature cure is one of the key reasons UPR have enjoyed such widespread use.<sup>1</sup>

Room temperature cure involves generating the high free-radical flux using an organic peroxide such as methyl ethyl ketone peroxide (MEKP). MEKP is a stable organic peroxide that decomposes rapidly in the presence

of certain metallic carboxylate salts. Cobalt salts have been used since the late 1800's in the coatings industry to promote oxidative cure in films of alkyd paint. Most active transition metals promote the uptake of oxygen, but only cobalt and manganese are known to promote both oxygen uptake and catalytic decomposition of hydroperoxides into free-radicals. The decomposition proceeds by an oxidation/reduction reaction as depicted in Figure 1.<sup>2</sup>

While cobalt is a very effective "promoter" of peroxide decomposition, some unsaturated polyester formulations need a faster cure time without sacrificing gel time. Additional cobalt would give faster cure but doing so may reduce gel time significantly.<sup>3</sup> A common method of adjusting cure speed without adversely affecting gel time involves the use of copromoters. Copromoters can be based on various chemistries such as amines, amides, and acetoacetates. Figure 2 depicts common copromoters used in the UPR industry past and present.

As with most choices, using one of the more effective copromoters such as dimethyl aniline (DMA) or dimethyl acetoacetamide (DMAA) has advantages and disadvantages. DMA is very effective for most systems, but suffers from greater color development. DMAA offers much improved color, but is less effective than DMA. Formulators can increase DMAA levels to compensate, however its water solubility may lead to water sensitivity.

A "reactive copromoter" that provides copromotion activity while having functional groups that allow incorporation into the cured polymer matrix could have utility in the industry. Ideally, the reactive copromoter would also serve as a non-HAPS styrene replacement. This could allow formulators to use established polyester resins with little need for molecular weight reduction or polymer branching. Molecules that would be particularly suited for use as reactive copromoters are combinations of the acetoacetate functionality for copromotion and a methacrylate or acrylate functional group for free-radical curing. One commercially available molecule described is acetoacetoxyethyl methacrylate (AAEM). The purpose of this paper is to investigate the use of AAEM as a reactive copromoter in unsaturated polyester formulations.

### Acetoacetoxy Group Interaction with Cobalt

Two particularly successful classes of copromoters are acetoacetamides and acetoacetates. Both classes of compounds contain the acetoacetoxy group. The mechanism cited for copromotion activity involves complexation of the cobalt +2 or +3 cation through the 1,3-dicarbonyl structure as depicted in Figure 3. This stabilization effect reduces the activation energies needed for oxidation/reduction, making the cobalt more effective at decomposing hydroperoxides. More effective hydroperoxide decomposition produces a quicker and larger free-radical flux enhancing resin cure. Acetoacetamides are generally more effective than acetoacetates due to the increased stabilization offered by the

greater electron-donating potential of nitrogen versus oxygen. Nevertheless, acetoacetates are still successfully used in the UPR industry.

## Experimental

### Resin Synthesis

Three types of unsaturated polyester resin were chosen for synthesis and evaluation. Computer controlled reactors were utilized for the synthesis using a two-stage reaction. Each resin was characterized (Figure 4), isolated neat, and later diluted to 57.9 wt. % resin solids with drum grade styrene. All three were formulated with a target number average molecular weight of 2400 daltons at an acid number of 10 – 15.

Resin 1 (HI-MAN) was a neopentyl glycol/propylene glycol (85 / 15 mole ratio) formulation using 100 percent isophthalic acid. The maleic anhydride level of resin 1 was three times the isophthalic acid level giving a highly reactive resin at a 3:1 molar ratio.

Resin 2 (STD-ISO) was a typical industry standard neopentyl glycol/propylene glycol (85 / 15 mole ratio) formulation using 100 percent isophthalic acid and a maleic anhydride molar ratio of 1:1.

Resin 3 (CHDA) also used neopentyl glycol/propylene glycol (85/15 mole ratio) but the isophthalic acid was replaced with non-aromatic 1,4-cyclohexanedicarboxylic acid. The maleic anhydride: diacid mole ratio was 1:1 for this resin.

### Gel Time and Cure Studies

Each of the three diluted resins was divided into nine aliquots for subsequent addition of either AAEM or DMAA and additional styrene needed to equalize the unsaturation level in each sample (Figure 5). Equal unsaturation levels were used to minimize differences in cure characteristics dependant on the number of double bonds available for polymerization. For each resin, one aliquot was prepared with no copromoter added. Previous exploratory work showed DMAA to be approximately 8 - 10 times more effective than AAEM as a copromoter. The aliquots with AAEM were prepared at 2, 4, 6, 8, and 10 wt. %. The DMAA samples were prepared at 0.2, 0.4, 0.6, 0.8, and 1.0 wt. %. Each aliquot was initiated with 1 wt. % MEKP. A 50 g sample was weighed in a paper cup for the gel time test and a 35-g sample was weighed in a quart-size paint can lid to form the hardness disk for Barcol testing.

Gel time, time to peak exotherm temperature, and peak exotherm temperature were measured using a Sunshine Gel Time meter and a type J thermocouple.

Barcol Hardness was measured at 2 hours and 24 hours using a Barber-Coleman Portable Impressor Hardness Tester GYZJ-935. Pendulum Hardness was measured at 2 hours and 24 hours using a Byk Gardner Pendulum Hardness Tester with Konig Pendulum.

### Gel Coat and Laminate Preparation

A master batch gel coat pigment grind was prepared with 97.31 g of 58 wt. % resin solution and 141.41 g of R-902 TiO<sub>2</sub> pigment. The TiO<sub>2</sub> was slowly added to the resin solution under agitation provided by a Cowles disperser blade. After the pigment was wet, the grind was processed at 5000 RPM for 10 minutes yielding a Hegman of 7+. This was followed by let down with 430.66 g of 58 wt. % resin solution. The formulation was completed by incorporation of 10.62 g of fumed silica. The fumed silica was dispersed at 5000 RPM for 10 minutes. Gel coat yield was 680 g at a TiO<sub>2</sub> level of 21 wt. %.

Each of the three gel coat master batches were divided into five samples for preparation of the laminates. Gel coats were formulated for each resin type to contain 0, 2, and 10 wt. % AAEM, as well as, 0, 0.2, and 1.0 wt. % DMAA. The viscosity and thixotropic index were determined for each of the gel coat preparations.

Each laminate was prepared by making 35-mil wet draw down of catalyzed gel coat onto a polished, mold-release treated glass plate. The cure package was as follows:

- 106 g prepared gel coat master batch
- 0.44 g 6% cobalt octoate (0.4% promoter)
- 0.28 g air release additive (0.25% air release)
- 0.025 g HQ (250 ppm inhibitor)
- 1.10 g 9% active oxygen MEKP (1% catalyst)

The cobalt octoate, air release additive, and HQ were added to the gel coat, stirred gently and allowed to mix for 30 minutes prior to use. The resulting draw down was allowed to cure until slightly tacky. The laminating resin and fiberglass were applied to the gel coat using hand lay-up and a roller. The laminating resin was a commercial DCPD product, *Polylite* 33234 from Reichhold, targeted for general purpose marine applications and catalyzed with 1.0 wt % MEKP. The fiberglass mat used was commercial 1.5 oz. chopped strand material type M-723. The final resin: fiberglass ratio was 70:30. The laminate was allowed to cure overnight followed by subsequent post curing at 66° C for two hours. The laminates were cut into required sizes for accelerated weathering via UVA-340 and hot water blister resistance per the methods listed in Figure 6.

### Evaluation of Hot Water Blister Resistance

Hot water blister resistance was conducted at 66°C with evaluation at 100 hour intervals for 1000 hours. ASTM D 714 "Evaluating Degree of Blistering of Paints" was used for the evaluation. This method was selected because it is based on pictorial standards thus

better reproducibility in panel judging. The method ranks blister size inversely, i.e. the larger the number the smaller the blister. Frequency ratings are word designations of few, medium, medium dense, and dense. Percent water uptake was also determined for each panel.

## Results and Discussion

Similar trends were observed for the cure characteristics for the three resin types. The data presented are for the standard NPG/PG/ISO resin (Resin 2) except when noted.

**Gel Time (GT)** - Figure 7 illustrates the effect of DMAA and AAEM on gel time. The greatest effect occurs between the control with no copromoter and the initial addition level of 2 wt. % for AAEM and 0.2 wt. % for DMAA. Gel time decreased from 5.5 minutes to 1 - 1.5 minutes at the lowest addition level evaluated. The effect diminished with increasing copromoter/reactive copromoter concentration. The data supported previous work showing DMAA to be approximately 10 times more effective than AAEM as a copromoter only.

**Time to Peak Exotherm (TPE)** - Figure 8 depicts the effect of copromoter/reactive copromoter on time-to-peak exotherm for the NPG/PG/ISO resin. The data again show the relative effectiveness of DMAA compared to AAEM. The same pattern described for GT holds for TPE. The greatest effect was upon initial addition of copromoter/reactive copromoter. Less change was observed with subsequent addition of either copromoter.

**Peak Exotherm Temperature (PET)** - PET displayed similar effects between the control and initial addition of copromoter/reactive copromoter. The data show increasing DMAA levels over the initial amount gives slightly higher PET before leveling off. The reactive copromoter candidate behaved differently. The maximum effect on PET was observed at about 4 wt. %. From this point, increasing AAEM levels decreased PET. The drop could be attributed to a couple factors. First, the methacrylate double bond of AAEM may be less reactive than the styrene double bond. This may not be observed at lower levels when the copromotion activity of AAEM was significant. As AAEM level increases, the lower reactivity begins to counteract copromotion giving a lower PET. Another factor may be mobility/diffusion effects. AAEM chelation with cobalt could also be reducing methacrylate double bond availability for polymerization.

**Barcol Hardness** - Hardness development for the resin systems showed no significant differences between DMAA and AAEM. The data did not support the hypothesis of high AAEM levels reducing the hardness of the cured resin. Both were effective at curing the resin to a consistent hardness with 98% of the hardness developed in 2 hours. Figure 10 summarizes the hardness development 24 hours post cure for the resins. König Pendulum Hardness gave similar results as Barcol Hardness and is not presented.

**Gel Coat Viscosity Effects** - Viscosity effects were dependant on the resin system and the level of AAEM used to replace styrene. AAEM had little effect on gel coat viscosity as depicted in Figure 11. DMAA did have an effect on viscosity dependant on the resin type. DMAA resulted in higher viscosity compared to AAEM. It was thought the water carried in by the DMAA solution could cause an increase in hydrogen bonding potential with the fumed silica thixotrope thus raising viscosity. The phenomenon was not observed in the CHDA based resins. No explanation can be offered for this observation. Overall, gel coat viscosity was not affected by use of the reactive copromoter in the resin systems evaluated. A greater effect was seen with the DMAA aqueous solution.

**Effect on Styrene Level** - A reactive copromoter such as AAEM offers another benefit from an EPA MACT compliance perspective. AAEM is considered non-HAPS by the EPA and can be used to replace a portion of the styrene. There are other styrene replacements including vinyl toluene, alpha-methyl styrene, and divinyl benzene. However, none give the advantage of both copromotion activity and act as a non-HAPS reactive diluent. Figure 12 illustrates the effect of increasing AAEM levels on HAPS-level for Resin 2, the typical NPG/PG/ISO resin. As seen in the graph, using 3.5 wt. % AAEM would allow a gel coat formulator to reach the 33 wt. % HAPS level required to meet MACT compliance. This assumes styrene as the only HAP in the system. Considering the efficacy AAEM, this level roughly approximates the typical 0.3 wt. % concentration of DMAA used in many formulations.

**UVA-340 Accelerated Weathering** - Results for the high maleic Resin 1 are not discussed due to the similarity with Resin 2. Conversely, 60° gloss data will not be discussed as the data reflected similar trends as 20° gloss. Color analysis data is presented for delta b\* color since this was the driving factor for overall color change.

As depicted in Figures 13 and 14, gloss retention data for AAEM exhibited similar characteristics as DMAA. The graphs show the effect of each copromoter at two levels using Resins 1 and 2. The standard NPG/PG/ISO resin (Figure 13) showed greater initial differentiation than the CHDA based series (Figure 14). Of these, the 10 wt. %

AAEM – PIA sample behaved peculiarly. The initial gloss of this sample decreased quickly after the first 100 hrs of exposure then leveled off. No explanation could be attributed to this observation. Other than this anomaly, weathering for both resin types was similar until reaching approximately 500 – 600 hours. At this point, the 1 wt. % DMAA - CHDA sample began a rapid decline. The decline was also present in the PIA samples but not as abrupt. In both resins, the control sample made without copromoter performed best. However, the cure of these formulations may be questionable.

AAEM reduced the yellowing of the gel coat formulations compared with DMAA. The improvement was observed for all three resin types. Figures 15 and 16 clearly illustrate the benefit. Again, the best anti-yellowing formulation was the control without either copromoter. One interesting aspect involving resin type could be seen with the yellowing data. Note in Figure 15 with the PIA resin type, increasing yellowness appears related to the copromoter type, i.e. AAEM has less color development than DMAA. However, color development was more concentration dependant with the CHDA based resin type per Figure 16. It was not clear what caused this occurrence. It was suspected the UV absorbance differences between PIA and CHDA resins are at play.

In addition to the UVA data, Xenon Arc data was to be developed for comparison and verification. Unfortunately, equipment issues prevented the data from being generated in time for this paper.

**Osmotic Blister Resistance** – Results for the high maleic Resin 1 are not discussed due to the similarity with Resin 2. Osmotic blistering results revealed only minor differences in performance of AAEM versus DMAA. Water uptake data for the PIA resin was similar except for the 10 wt. % AAEM sample per Figure 17. Note this was the same sample that gave peculiar results in UVA-340 weathering. The water uptake data for CHDA showed more differentiation as seen in Figure 18. The data suggests DMAA may make the CHDA based samples slightly more susceptible to moisture uptake.

Water uptake measurement is one method of determining the effect of osmotic blistering on test panels. However, the visual effect of osmotic blistering can manifest itself in many ways. The average water pick-up for the PIA samples was 0.44 wt. % and 0.50 wt. % for CHDA. One would expect appearances to be similar, but the panels based on PIA had better visual appearances compared to the CHDA based panels. Note the blister size development for each resin series in Figure 19. The PIA based samples generally had smaller uniform blisters after 1000 hours exposure. Conversely, CHDA samples had larger blisters which support the greater water uptake results observed for CHDA. Blistering frequency was also slightly less with PIA resins versus CHDA per Figure 20.

AAEM did show a color development advantage over DMAA in osmotic blistering, specifically Delta b\* color. Note in both Figure 22 and 23 the sample with the highest color development in both resin cases was the 1 wt. % DMAA level. The greatest difference was seen with the CHDA based resin.

## Conclusions

Use of AAEM as a reactive copromoter provides gel coat formulators with three advantages. First, it acts as a copromoter by improving the reactivity of sluggish curing resins. Secondly, the methacrylate functional group provides a means of tying up the copromoter in the cured polymer matrix. And thirdly, as a low viscosity non-HAPS liquid capable of polymerization, AAEM functions as a styrene replacement.

Hardness was not significantly affected when evaluated in the three resin systems at levels up to 10 Wt. %. This observation indicates the material was being adequately polymerized into the polymer backbone instead of acting as a plasticizer.

When considered exclusively as a copromoter, AAEM is about one-tenth as effective as DMAA. However, the benefit of HAPS level reduction in composite resin formulations makes the use of AAEM or other reactive copromoters attractive considering the ever increasing regulations faced by the composites industry. A good starting point level for AAEM was shown to be approximately 3 Wt. %. Deviation was noted in PET using higher AAEM levels.

The limited UVA-340 weathering data showed minor differences between AAEM and DMAA. Gloss retention was comparable except for the highest DMAA level. This sample deteriorated rapidly after ~ 700 hours exposure. Color development was acceptable with Delta b\* showing the greatest change. Color change was molecule dependant for PIA and more concentration dependant for CHDA. In both cases, the highest 1 wt. % DMAA samples gave the greatest color development.

The data did not identify significant differences for osmotic blister resistance. Overall, blistering followed the progression generally observed in the industry. PIA has better blister resistance than CHDA. AAEM did give better color stability at higher levels. It is known that DMAA solutions discolor rapidly with heat thus high levels of DMAA gave the greatest color development.

In conclusion, AAEM can be successfully used as a reactive copromoter in room temperature cured unsat resin systems. AAEM was found to be about one-tenth as effective as DMAA in the resin types evaluated.

## Citations

- 1 Rosato, Donald V. and Rosato, Dominick V., *Reinforced Plastics Handbook - 3<sup>rd</sup> Ed.*, Elsevier Inc., New York, **1995**
- 2 Hare, Clive H., *Protective Coatings - Fundamentals of Chemistry and Composition*, Technology Publishing Company, Pittsburgh, **1994**
- 3 Golob, Dennis J., *Performance Payoff in Polyester Cure Analysis*, Modern Plastics, June **1987**

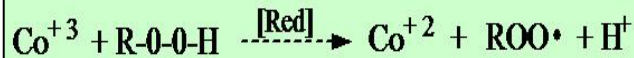
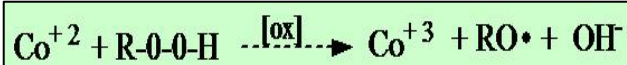


Figure – 1. Cobalt Catalyzed Hydroperoxide Decomposition

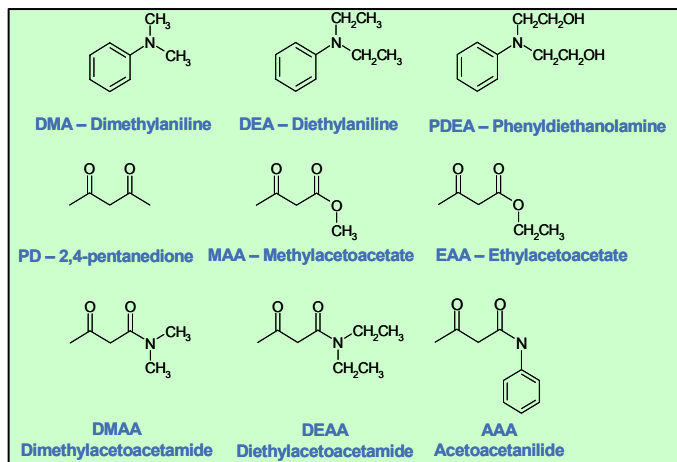


Figure – 2. Commonly Used Copromoters

Parameter	Resin 1 Hi-MAN	Resin 2 Std. Iso	Resin 3 CHDA
MW <sub>n</sub>	3393	3060	3160
MW <sub>w</sub>	10895	7661	19698
PD	3.21	2.50	6.23
Acid No.	14	15	19
Tg, C	24	35	11
ICI @ 175°C	12.2	16.0	8.7
% Fumarate	86.4	86.0	91.8

Figure – 4. Resin Characterization

Resin Solution (Resin 1, 2, or 3)						
Aliquot ID	g Resin	g Styrene	Molar Eq.		Copro-moter Weighed, g	Wt% AAEM
			Styrene	Wt AAEM, g = Eq. Styrene		
AAEM0	55	45	0.43	0.0	0.0	0.0
AAEM2	55	44	0.42	2.1	2.1	2.0
AAEM4	55	43	0.41	4.1	4.1	4.0
AAEM6	55	42	0.40	6.2	6.2	6.0
AAEM8	55	41	0.39	8.2	8.3	7.9
AAEM10	55	40	0.38	10.3	10.3	9.8

Aliquot ID	g Resin	g Styrene	Molar Eq.		g Copromoter	
			Styrene	g DMAA @ 80%	Weighed	Wt% DMAA @ 100%
DMAA0	55	45	0.43	0.0	0.0	0.0
DMAA2	55	45	0.43	0.3	0.3	0.2
DMAA4	55	45	0.43	0.5	0.5	0.4
DMAA6	55	45	0.43	0.8	0.8	0.6
DMAA8	55	45	0.43	1.0	1.0	0.8
DMAA1	55	45	0.43	1.3	1.3	1.0

0.30g 6% Cobalt Octoate/ 1.0 g MEKP added to each total solution as the cure package.  
50 g of material weighed for gel test and 35 g material weighed for Barcol Hardness Disk.

Figure – 5. Compositions Evaluated

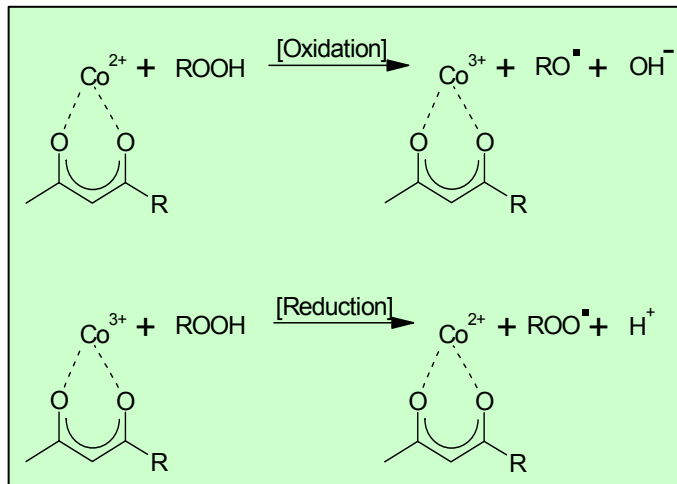


Figure – 3. Acetoacetoxy Interaction With Cobalt

UVA - 340	Blister Resistance
Method Name: UVA -340, G154 Cycle 1	Method Name: None
Purpose: Common Outdoor Simulation	Purpose: Simulate extended exposure to water
Inner Filter: NA	Machine: Apparatus built in house – 10 exposure slots
Outer Filter: NA	Evaluation Cycle: Varies – 100 hour cycle used
Lamp: Fluorescent UV, peak @ 340 nm	Water Type: De-mineralized water
Irradiance [W/m2/nm]: 0.89 @ 340 nm	Water Temperature: 66°C (150° F)
Cycle: 8 hr light @ 60°C	
4 hr dark with condensation @ 50° C	

Figure – 6. Weathering and Blister Resistance Test Methods

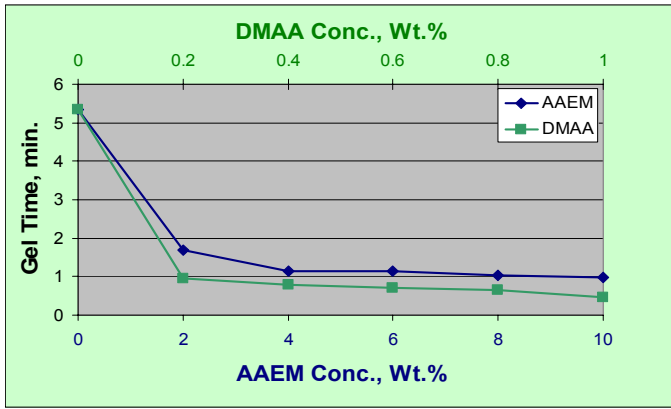


Figure – 7. Gel Time Comparison for Standard NPG/PG/ISO Resin

Material/Concentration	Resin 1	Resin 2	Resin 3
	NPG/PG/ISO HI-Maleic	NPG/PG/ISO	NPG/PG/CHDA
Control	69	74	80
AAEM / 2%	84	89	88
AAEM / 4%	84	88	88
AAEM / 6%	84	87	85
AAEM / 8%	ND	88	85
AAEM / 10%	ND	87	89
DMAA / 0.2%	90	88	90
DMAA / 0.4%	88	89	87
DMAA / 0.6%	ND	91	87
DMAA / 8%	ND	ND	ND
DMAA / 1.0%	ND	ND	ND

ND – Not determined, resin gelled almost immediately after adding peroxide.

Figure – 10. 24-Hour Barcol Hardness

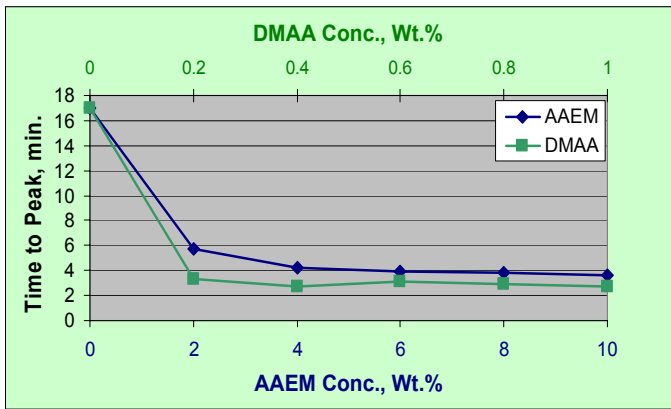


Figure – 8. Time to Peak Exotherm for Standard NPG/PG/ISO Resin

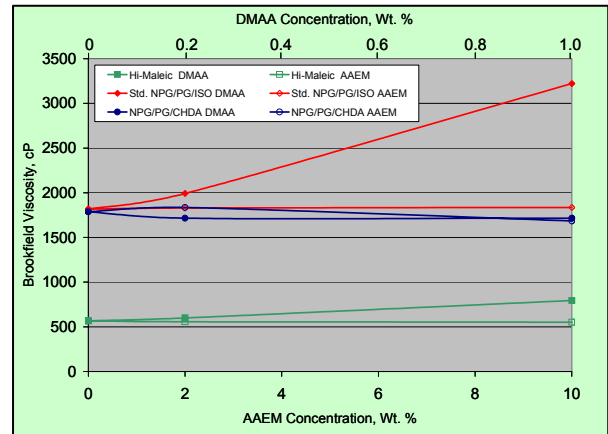


Figure – 11. Gel Coat Viscosity

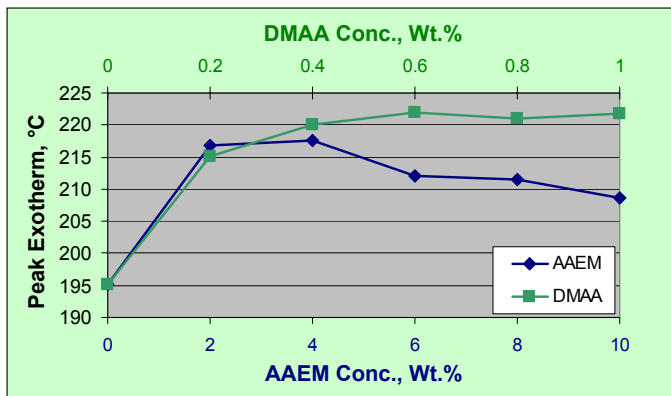


Figure – 9. Peak Exotherm Temperature for Standard NPG/PG/ISO Resin

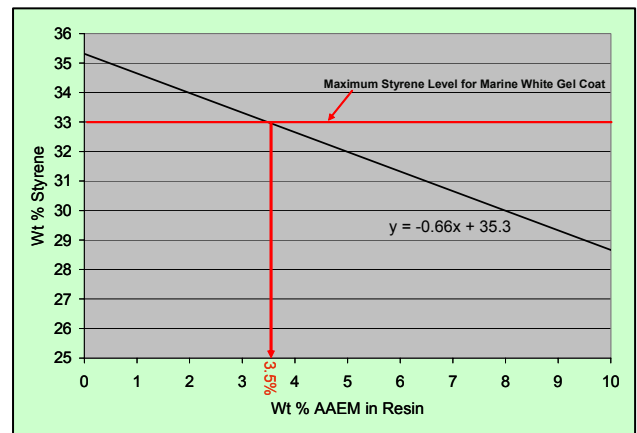
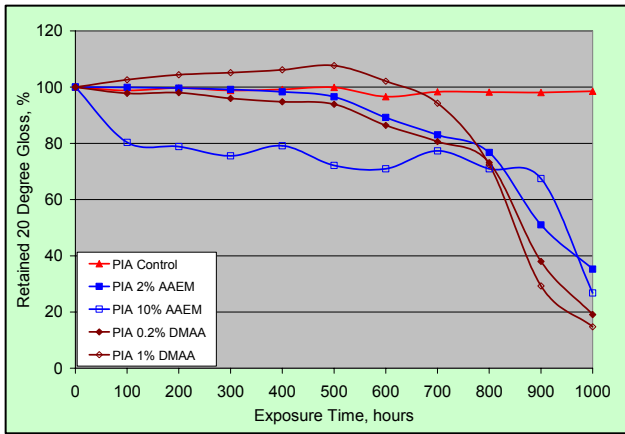
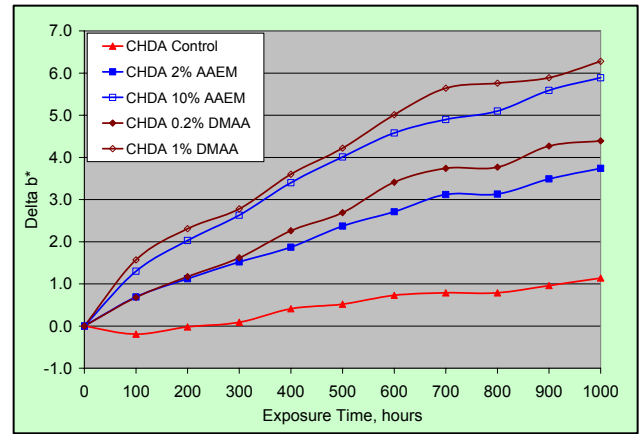


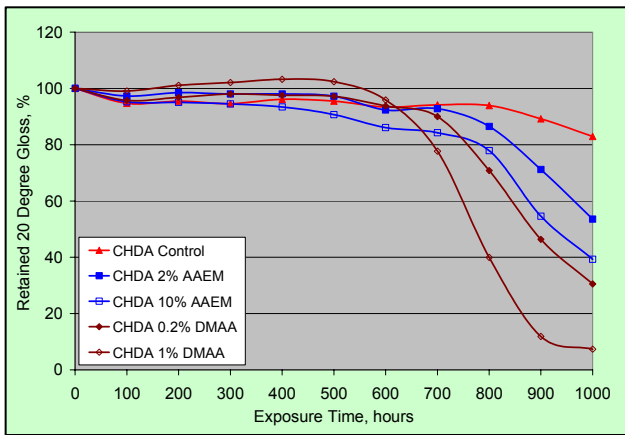
Figure – 12. Reduction in Styrene Level



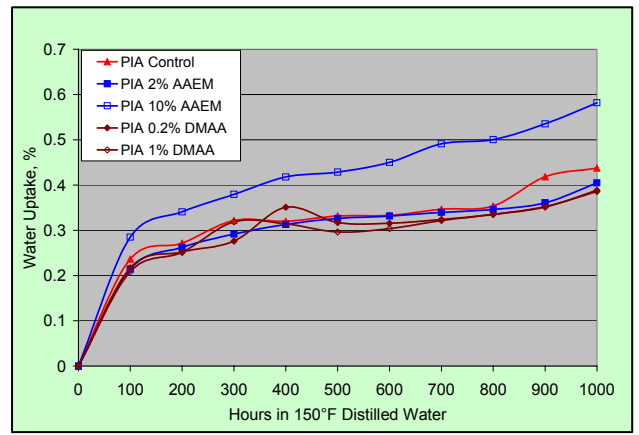
**Figure – 13. 20° Gloss Retention for Standard NPG/PG/ISO Resin – UVA 340 Exposure**



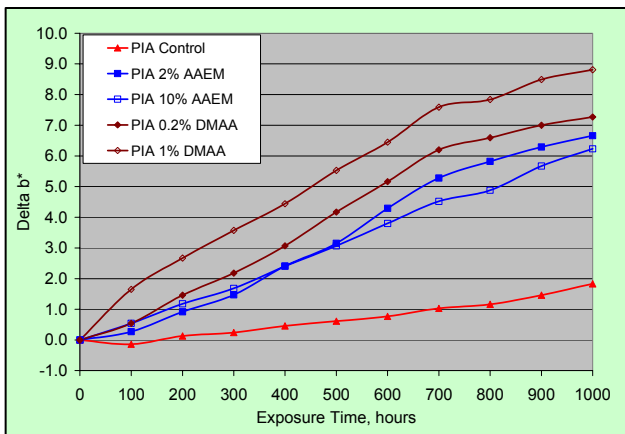
**Figure – 16. Delta b\* Color for NPG/PG/CHDA Resin – UVA 340 Exposure**



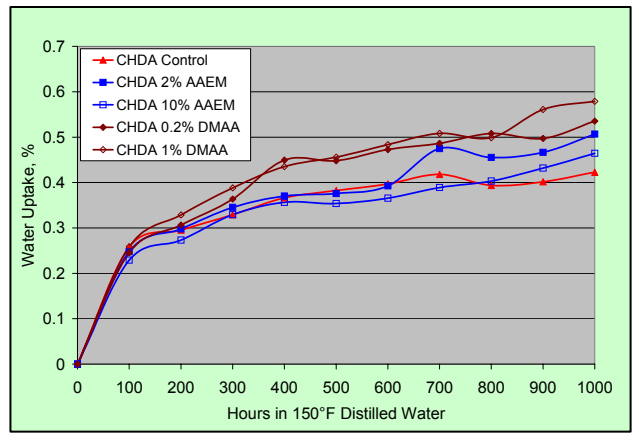
**Figure – 14. 20° Gloss Retention for Standard NPG/PG/CHDA Resin – UVA 340 Exposure**



**Figure – 17. Water Uptake for NPG/PG/PIA Resin – Osmotic Blister Resistance**



**Figure – 15. Delta b\* Color for NPG/PG/PIA Resin – UVA 340 Exposure**



**Figure – 18. Water Uptake for NPG/PG/CHDA Resin – Osmotic Blister Resistance**

Hours>	0	200	400	600	800	1000
PIA Control	None	None	None	8	6	6
PIA 2% AAEM	None	None	None	8	8	8
PIA 10% AAEM	None	None	None	8	8	8
PIA 0.2% DMAA	None	None	None	8	8	8
PIA 1% DMAA	None	8	8	8	8	8
CHDA Control	None	6	4	2	2	2
CHDA 2% AAEM	None	8	6	4	4	4
CHDA 10% AAEM	None	None	6	2	2	2
CHDA 0.2% DMAA	None	None	4	2	2	2
CHDA 1% DMAA	None	6	4	2	2	2

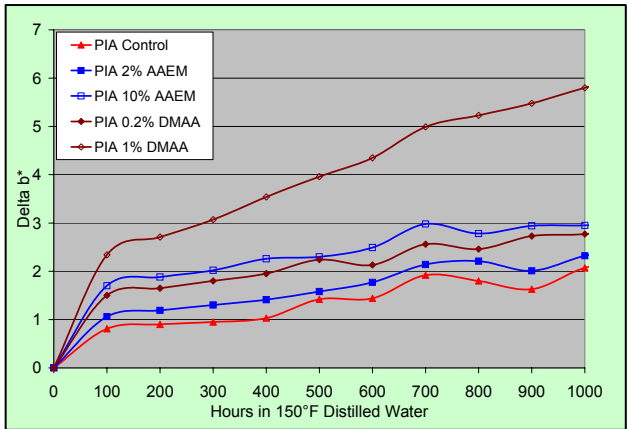
ASTM D-714 "Evaluating Degree of Blistering of Paints"

**Figure – 19. Blister Size Ratings – Osmotic Blister Resistance**

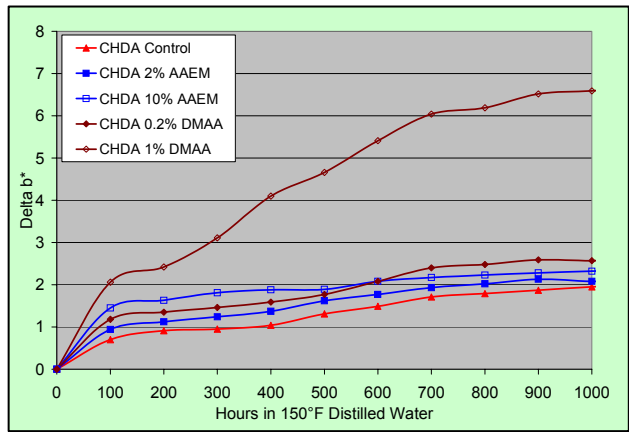
Hours>	0	200	400	600	800	1000
PIA Control	None	None	None	Medium	Medium	Dense
PIA 2% AAEM	None	None	None	Medium	Medium	Medium
PIA 10% AAEM	None	None	None	Few	Few	Few
PIA 0.2% DMAA	None	None	None	Medium	Medium	Medium
PIA 1% DMAA	None	Medium	Medium	Medium	Medium	Medium
CHDA Control	None	Medium	Medium	Medium	Medium	Medium
CHDA 2% AAEM	None	Few	Medium	Medium	Medium	Medium
CHDA 10% AAEM	None	None	Medium	Few	Dense	Medium
CHDA 0.2% DMAA	None	None	Medium	Medium	Medium	Medium
CHDA 1% DMAA	None	Medium	Medium	Medium	Medium	Medium

ASTM D-714 "Evaluating Degree of Blistering of Paints"

**Figure – 20. Blister Frequency Ratings – Osmotic Blister Resistance**



**Figure – 21. Delta b\* Color for NPG/PG/PIA Resin – Osmotic Blister Resistance**



**Figure – 22. Delta b\* Color for NPG/PG/CHDA Resin – Osmotic Blister Resistance**

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**Author(s):**

**Jeffery E. G. Powell**

Eastman Chemical Company  
Advanced Technical Service Representative  
Resin Intermediates Technical Service Laboratory  
Unsaturated Polyester Resins

**Angela H. Honeycutt**

Eastman Chemical Company  
Technologist  
Resin Intermediates Technical Service Laboratory  
Unsaturated Polyester Resins