

# NOVEL CURING AGENT TECHNOLOGY FOR HIGH SOLIDS EPOXY COATINGS

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Abstract: Reduced VOC and increase solids in solvent borne epoxy formulations, give shorter pot lives, longer dry times, reduced flexibility, amine blush and poor surface appearance. [Theoretical treatment explains the causes of some of these problems.] A novel curing agent is described which addresses these limitations of epoxy coatings.

## INTRODUCTION

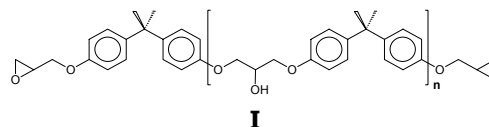
In the epoxy coatings market there is a strong drive towards higher solids formulations. Whereas traditional epoxy formulations were typically in the range of 40-50% volume solids, state-of-the-art high solids formulations are now 80-90% volume solids or higher. These new systems offer the advantages of lower VOC and reduced site emissions along with higher film build and reduced labor costs. Unfortunately, these advantages usually come at the cost of some significant performance and handling compromises.

## CHEMISTRY OF TRADITIONAL AND HIGH SOLIDS SOLVENT BORNE EPOXY COATINGS

The majority of 'old-fashioned' solvent borne epoxy paints utilized a 'solid' epoxy resin and a polyamide curing agent with a viscosity in the range of 400,000 cP at room temperature. To reduce viscosity and increase solids, high solids formulations are usually based on 'liquid' epoxy resin and a polyamide curing agent with a much lower viscosity, typically in the range of 15,000-50,000 cP.

Both standard liquid and solid epoxy resin are oligomers derived from bisphenol-A, with chemical structure **I**. They differ in the

average value of  $n$ . For liquid epoxy resin  $\overline{M}_n$  is about 380, the viscosity is about 12,000 cP at room temperature, and  $n \cong 0.15$ . There are several grades of solid epoxy resin, but the one most commonly used in coatings has an  $\overline{M}_n$  of about 1050, with  $n \cong 2.5$ . Because of its physical state, the viscosity of solid epoxy resin cannot be measured directly, but if viscosity vs. % solids is plotted, the extrapolated value of this resin's viscosity is in the millions of cP.



Polyamide resins are generally based upon the step-growth polymerization of triethylenetetramine (TETA) with a mixture of dimer fatty acids and a C<sub>18</sub> fatty acid (most usually tall oil fatty acid, or TOFA). Dimer fatty acid itself is a complex mixture of branched and cyclic products consisting of primarily C<sub>36</sub> diacids, C<sub>54</sub> triacids, etc.

There is a tendency for the amide bonds to be formed in this reaction on the primary amines of TETA in preference to the secondary amines. Thus, for most amides formed, two amine hydrogens for reaction with epoxide are eliminated, since the amide N-H does not react with epoxide. The molecular weight of the polyamide is controlled by the ratio of amine to acid, and by the amount of TOFA, which acts as a chain stopper. The reactions are under equilibrium control. Thus, when a higher ratio of amine to acid is employed so as to yield a lower molecular weight polyamide, there is generally a higher level of free TETA in the product as predicted by Le Chatelier's principle.

### Pot Life

Pot life ends when the viscosity of the paint increases to the point where acceptable application can no longer be achieved. Clearly, in a two component thermosetting coating this is a function of the degree of conversion of the reactants. The kinetics of the reaction of epoxy resins with an amine curing agent are somewhat complex, because there are mixtures of 1° and 2° amines present, and because the reaction is strongly catalyzed by hydroxyl groups that are formed during the reaction.<sup>i</sup> However, in the presence of an alcohol solvent or an accelerator such as a phenol, the concentration of OH groups is more-or-less constant, and the kinetics of the reaction are then approximately second order. In other words, the rate of consumption of epoxide is nearly proportional to the concentration of amine times the concentration of epoxide, with a proportionality constant equal to some rate constant,  $k$ :

$$\frac{-d[E]}{dt} = k[E][A]$$

If the density of the solvent and resins are known, it is a simple matter to calculate the concentration of epoxide groups in formulations of varying VOC levels. The data for theoretical clearcoats is shown in Table 1. A VOC of about 5 lb/gal was typical of a low solids solid epoxy resin formulation, and 3.5 lb/gal would represent about the lowest VOC achievable in such formulations. Note that at this VOC, *the concentration of epoxide groups more than doubles* upon changing from solid to liquid epoxy resin.

Table 1 Calculated % solids and [epoxide] for clearcoats of varying VOC content, with epoxide equivalent weights of typical solid and liquid epoxy resins. Calculations assume that resin and curing agent both have a density of 1.15 g/mL and are present at 1:1 stoichiometry. The curing agent has an equivalent weight of 100 g/N-H, and the solvent density is 0.85 g/mL.

By inserting the epoxide concentration into the integrated form of a second order rate equation,<sup>ii</sup> it is possible to calculate the time to reach any degree of conversion. Data for 50% (half-life) and 25% (quarter-life) conversions

are shown in Figure 1. A rate constant of 0.0001 L/mol-sec was assumed, which is within the range of reported second order rate constants for amines with aromatic glycidyl ethers at room temperature.<sup>iii</sup> At what degree of conversion pot life will end depends on the particular system studied, and the absolute values obtained are not so important as the trends.

With the highest VOC formulation of solid epoxy resin, the half-life is calculated to be 9.5 hours. By simply reducing VOC to 3.5 lb/gal, the half-life decreases to 3.21 hr., whereas switching from solid to liquid resin further reduces the half-life to 0.69 hr. At 100% solids, the half-life is only 11 minutes! The basic trends are in good agreement with the enormous decreases in pot that are experienced in actual practice as VOC has been continuously reduced. Thus, the decrease in pot life in high solids formulations is simply the result of the increased concentration of reactive groups, and chemical kinetics. (Fig.1)

### Dry speed, flexibility, hardness development and solvent resistance.

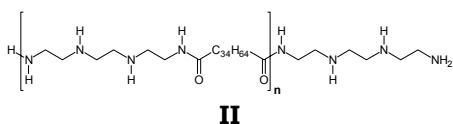
It is frequently found that high solids epoxy coatings have much slower dry times than conventional solids paints. A useful concept is that a coating will appear to be dry when the film does not appreciably flow under light finger pressure. Since viscosity is by definition resistance to flow, it follows then that the state of dry will also be related to viscosity. It has been reported,<sup>iv</sup> for example, that a coating with a viscosity greater than 1,000,000 cP will pass 'dry-to-touch.' A much higher viscosity is required, to pass a blocking test.

Conventional epoxy coatings generally pass dry-to-touch and dust free tests in a matter of minutes. This is probably too short a time for chemical reactions to play a significant role in the drying process. Since they are based on a solid epoxy resin (with a viscosity in the millions of cP) and a polyamide resin with a viscosity of about 400,000 cP, it is quite reasonable that once most of the solvent flashes and perhaps a small amount of chemical reaction has occurred, the film will become dry-to-touch. Drying that is solely

dependent on solvent evaporation is referred to as 'lacquer dry.'

To understand the differences in the drying behavior of high solids formulations, computer modeling of epoxy cure was conducted using Bauer's<sup>v</sup> program for Miller-Macosko<sup>vi</sup> calculations, modified by one of the authors to run in Microsoft Excel<sup>®</sup> so that the data can be easily plotted. For curing agents, idealized TETA-dimer acid oligomers (**II**) were chosen with values of  $n = 2$  for high solids, and  $n = 8$  for low solids.

The data required for the calculations is shown in Table 2, along with the calculated gel point. The weight average molecular weight as a function of conversion is given in Figure 2, and the crosslink density, calculated as the concentration of effective strands, is given in Figure 3.



The viscosity of concentrated polymer solutions is proportional to  $\overline{M}_w$  to the first power below the critical entanglement chain length.<sup>vii</sup> Since the low solids gives lacquer dry, we can reach a comparable  $\overline{M}_w$  and viscosity, depending on the accuracy of this modeling. The low solids system also gels at much lower conversion. However, at about 52% conversion, the crosslink density of the high solids composition begins to exceed that of the low solids composition, and the final crosslink density of the high solids system is about twice the low solids system.

As crosslink density increases, modulus increases for otherwise identical materials. Although there is some change in the ratio of epoxy resin to hardener in going from low to high solids, it is reasonable to assume that this increase in crosslink density would lead to higher modulus in this case. This would then be expected to yield higher hardness, as is normally observed when these changes are made. Unfortunately, the decrease in distance between crosslinks would be expected to lead to increased shrinkage, reduced flexibility, and increased internal stress.

This is indeed also usually observed when these formulation changes are made, since high solids epoxy coatings often perform poorly in impact, mandrel bend, and hygrothermal stress tests. Finally, solvent resistance is usually a function of crosslink density within families of similar materials. These calculations would suggest that solvent resistance at high degrees of conversion should be superior in a high solids formulation, which is also the usual real-world observation.

### Other Considerations

Epoxy coatings are susceptible to amine exudation and blush.<sup>viii</sup> Small mobile amine molecules migrate to the coating surface where they form a thin greasy layer with poor adhesive properties, known as exudate. Under high humidity conditions, these species at the surface can react with  $\text{CO}_2$  to form carbonates and carbamates, which give unsightly appearance and also interfere with adhesion. This phenomenon is referred to as amine blush. As noted earlier, high solids polyamides generally have higher concentrations of unreacted polyethylene amines present. Because of their low molecular weight and high polarity, these species are particularly prone to causing blush and exudate problems. Furthermore, the way this problem was traditionally handled was to mix the amine and epoxy, and wait about  $\frac{1}{2}$  to 1 hour before application, so reaction of the ingredients would improve compatibility. In high solids formulations, pot life is too short to allow for such a treatment.

High solids formulations also tend to have higher surface tensions than do low solids formulations. This is because the higher solids content usually requires the use of stronger solvents, and the resins themselves have higher concentrations of polar groups. This situation frequently leads to surface tension driven surface defects.

Conventional polyamide curing agents have very little tendency to crystallize due to their heterogeneous compositions. As their molecular weights are reduced, however, they frequently become more homogeneous, and any tendency to crystallize becomes more pronounced. This is another problem

frequently encountered in the development of high solids hardeners.

A well-designed high solids curing agent will exhibit a good balance of viscosity, dry speed, pot life, and flexibility. It must also be storage stable and resistant to amine blush. When crosslinked with liquid epoxy at ambient temperature, the new curing agent should develop a high degree of cure without vitrifying.<sup>ix</sup>

### EXPERIMENTAL APPROACH

Our first step in developing a high solids curing agent was to assemble target handling and performance properties as shown in Table 3. The targets were compiled from consideration of industry input along with the capabilities of available technology.

Research in our laboratories identified several new raw materials for the preparation of modified polyamide resins that showed promise in solving some of the problems discussed earlier, and that seemed to be a good starting point for the development of a curing agent that could meet the requirements of Table 3. Unfortunately, commercial considerations prevent discussion of the nature of those materials.

The hardener composition was optimized using statistical experimental design techniques. The ingredients in a composition of this type must sum to 100%. If a standard experimental design strategy is employed, with  $n$  ingredients, there will only be  $n-1$  degrees of freedom in the amounts of those ingredients, since the amount of the last ingredient is fixed. Normally, mixture designs are employed to deal with this problem. However, there are some disadvantages to the use of mixture designs. The mathematics underlying these designs is more complex than classical designs, and thus it is more difficult for the scientist using the technique to understand nuances of the design. It is usually more difficult to achieve high levels of orthogonality using mixture strategies. If some ingredients are present in small amounts, their effect on dependent variables is highly leveraged, and can lead to erroneous conclusions.

To avoid these problems, this composition was optimized using a classical, uniform precision response methodology. To overcome the need for ingredients to sum to 100%, the amounts of raw materials were handled as a series of ratios, all of which could be related to one component. For example, one variable was the ratio of total moles of amine to total equivalents of carboxylic acid. Not only did this strategy allow us to avoid the use of mixture designs, it also put the independent variables in a form that is more intuitive to a chemist. It was already mentioned that molecular weight in these compositions is controlled by the ration of amines to acids, and by making this a variable in the design, it's easy to use chemical expectations as a guide in setting up the experiments.

### NEW CURING AGENT DISCUSSION

#### Curing Agent Characteristics

This new curing agent composition is designed specifically for use in high solids solvent borne epoxy coatings. The handling and performance characteristics of the new curing agent are described in Table 4.

#### Formulating Guidelines

The best balance of dry speed and corrosion resistance was obtained at 1:1 stoichiometry or with a slight excess of liquid epoxy resin (e.g. 1.05 epoxy: 1.0 amine). At higher curing agent loadings (e.g. 1.0 epoxy: 1:15 curing agent) reduced humidity resistance was observed whereas at higher epoxy loadings longer dry times were observed.

Tertiary amine catalyst (tris-dimethylaminomethyl phenol) is effective at reducing dry time and increasing hardness albeit at the expense of pot life and flexibility. When tertiary amines are used, the curing agent level should be reduced to compensate for epoxy homopolymerization.

Solvent composition should reflect the solubility parameters of both the epoxy resin and the polyamidoamine curing agent<sup>x</sup>. Epoxies, with high polar solubility, are highly soluble in ketones. Polyamidoamines, with high hydrogen bonding solubility, are highly soluble in alcohols. Both liquid epoxies and polyamidoamines have relatively high non-

polar solubility and are soluble in aromatic solvents. The solvent mixture should also be hydrophobic if possible to avoid reduction of barrier properties. A blend of 40-50% high flash aromatic naphtha, 30-40% n-butanol, and 5-15% methyl propyl ketone provides a good balance of solvency, evaporation rate, hydrophobicity, and low HAPS content.

The new curing agent, when cured with liquid epoxy, develops a maximum Tg of 70 °C (DSC @ 10 °C/min.). For ambient temperature cure, a Tg of 50 ° -- 60 °C is desirable to obtain full cure without vitrification. Modest amounts of plasticizer such as benzyl alcohol can therefore be added without over plasticizing the polymer.

Starting point formulations utilizing the new curing agent in an anti-corrosive primer and a zero VOC brown finish coat are described in Table 5.

#### Low Temperature Cure Performance

When used as the sole curing agent, the new curing agent cures very slowly at low temperature. However, when the new curing agent (NCA) is used in combination with a low temperature modified cycloaliphatic amine (LTCA)<sup>xi</sup> that is specifically designed for low temperature cure, the system exhibits very good low temperature properties, as shown in Tables 7-9. The LTCA contributes fast reactivity and improved compatibility to the system. However, the LTCA used alone develops high crosslink density resulting in low flexibility and perhaps a shorter recoat window. The new polyamidoamine contributes flexibility, adhesion, extended time to MEK resistance and cost effectiveness to the system. By adjusting the ratio of the new curing agent to the LTCA, the formulator can control reactivity, flexibility, and development of crosslink density at various cure temperatures. LTCA levels of 25-50% have been very effective at 45° to 55°F. The tables below describe the low temperature performance of the new curing agent / LTCA blends.

#### SUMMARY

Kinetic modeling of the amine-epoxy reaction has shown that the large decrease in pot life that is observed in high solids coatings relative to traditional, low solids coatings can

be explained with a 2<sup>nd</sup> order equation with results that are in good agreement with field experience. Likewise, modeling of the molecular weight and crosslink density as a function of conversion using the recursive, statistical approach of Miller and Macosko explains the trends for increased dry times, improved solvent resistance and hardness, and reduced flexibility generally encountered as a result of VOC reduction. An understanding of these principles was of help in the development of a new high solids polyamidamine curing agent. This product offers a good balance of relatively fast dry speed, can be formulated to give to give acceptable pot life, and the resulting films have good flexibility, adhesion and corrosion resistance, and low blush and exudates relative to traditional low viscosity polyamides.

Table 1

<u>VOC</u> <u>(lb/gal)</u>	<u>Resin</u> <u>EEW</u>	<u>%</u> <u>Solids</u>	<u>[Epoxide]</u> <u>(eq./L)</u>
5.0	525	36.0	0.541
3.5	525	58.1	0.931
3.5	190	58.1	2.01
2.8	190	67.4	2.40
1.5	190	83.4	3.13
0	190	100	3.97

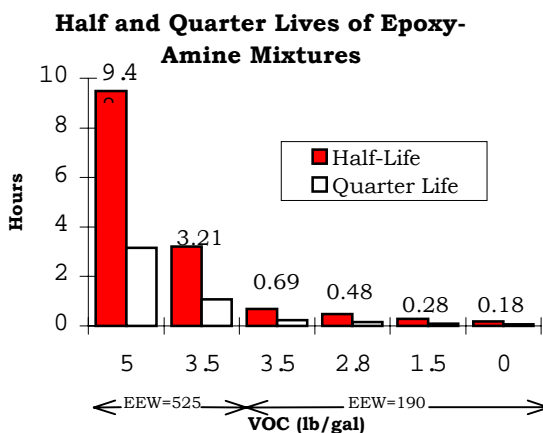


Fig. 1

Table 2  
Data Used for Miller-Macosko  
Model Calculations

	High Solids	Low Solids
Epoxide Resin Mol. Wt.	380	1050
Epoxide Resin Functionality	2	2
Curing Agent Mol. Wt.	1490	5522
Curing Agent Functionality	10	22
Stoichiometry	1:1	1:1
Calc. Gel Point	33.3%	21.8%
Final Xlink Density (mol/g)	0.001	0.0005
	18	86

Table 3  
Target Properties for New  
Curing Agent Technology

Hardener Viscosity (cP)	< 5,000
Mix Viscosity (cP)	< 10,000
Gel Time (min.)	> 60
Set-to-touch (hr.)	< 6
Hard Dry (hr.)	< 18
Forward Impact (in-lb)	> 60
Reverse Impact (in-lb)	> 40
EIS Pore Resistance (ohm cm <sup>-2</sup> )	> 10 <sup>9</sup>
Blush, 30 min. induction	None
Storage Stability	No Crystallization @ 40°F
% Reactive	100

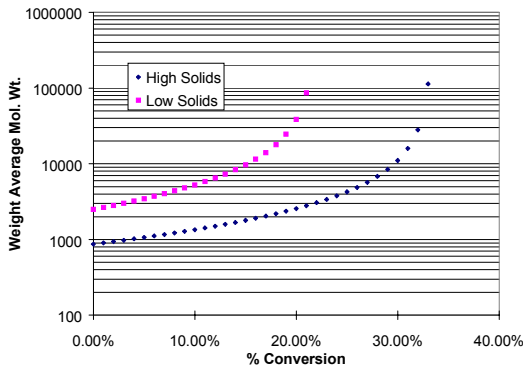


Fig. 2 - Weight Average Mol. Wt. Vs. Conversion

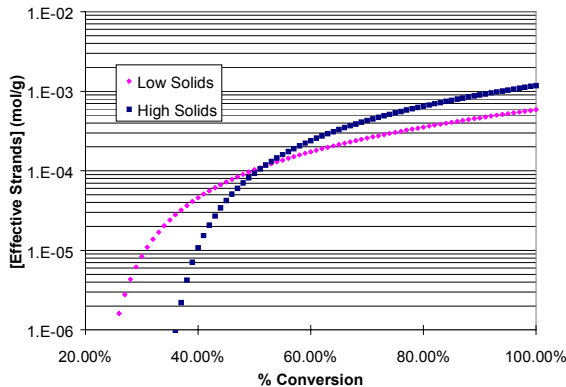


Fig. 3 - Crosslink Density vs. Conversion

Table 4  
Handling and Performance Characteristics of  
Novel Curing Agent<sup>xiii</sup>

Composition	Polyamidoamine
Reactive (%)	100
Viscosity (cP)	2,300
Mix Viscosity (cP)	4,400
Gardner Color	6
Specific Gravity (g/mL)	1.01
AHEW	124
Use Level, with Liquid Epoxy (phr, by weight)	66
Use Level, with Liquid Epoxy (phr, by volume)	76
EIS Pore Resist. (ohm cm <sup>-2</sup> ) 1 day / 30 day	> 10 <sup>10</sup> / > 10 <sup>10</sup>
T <sub>g</sub> with Liquid Epoxy (°C, DSC @ 10°C/min)	70
Reverse Impact (in-lb)	80
Pencil Hardness	F
Thin Film Set Time (hr.)	7
Gel Time (min./ 200 g mass)	60

Table 5  
Anti-corrosive Primer Formulation

RM	Pounds	Gallons
<b>A Side</b>		
Liquid Epoxy Resin	294.16	30.38
Pigment Wetting Agent	2.35	0.28
High Flash Naphtha	60.74	8.27
Wollastonite <sup>xiii</sup>	178.93	7.38
Red Iron Oxide	47.09	1.17
Aluminum Zinc Phosphate	<u>58.86</u>	<u>2.52</u>
	642.13	50.0
<b>B Side</b>		
New Curing Agent	194.02	23.29
n-Butanol	18.84	2.79
Benzyl Alcohol	28.25	4.18
Methyl Propyl Ketone	9.42	1.39
High Flash Naptha	39.79	5.42
325 Mesh Talc	94.18	3.96
Zeospheres 400	<u>164.81</u>	<u>8.97</u>
	549.29	50.0

Table 6  
Properties of Anticorrosive Primer Formulation

PVC	30%
VOC (g/L)	170
Weight Solids	88%
Volume Solids	80%
Viscosity	
A Side (cP)	1400
B Side (cP)	1600
Mix (cP)	1550
Pot Life (Time to 3,500 cP, hr.)	3
Set-to-touch (hr.)	6
Hard Dry (hr.)	16
Direct Impact (in-lb)	40
Reverse Impact (in-lb)	10
Anticorrosive Properties at 1000 Hr. Exposure	
Salt Fog (Field/Scribe)	10 / 9
Prohesion (Field/Scribe)	10 / 8

Table 7  
Zero VOC Brown Finish Formulation

RM	Pounds	Gallons
<b>A Side</b>		
Liquid Epoxy Resin	350.0	36.1
Pigment Wetting Agent	2.0	0.3
Exempt Solvent <sup>xiv</sup>	56.0	5.0
Chrome Green Oxide	<u>50.0</u>	<u>1.1</u>
	458.0	42.5
<b>B Side</b>		
Novel Curing Agent	230.0	27.8
Thixatropes	3.0	0.2
Flow Additive	2.1	0.2
Red Iron Oxide	20.0	0.50
Wollastonite	100	4.10
Barytes	50.0	1.40
Acetone	<u>55.0</u>	<u>8.2</u>
	461.0	85.0

Table 8  
Properties of Zero VOC Brown Finish

PVC	10%
VOC (g/L)	2
Weight Solids	88%
Volume Solids	84%
Initial Viscosity (cP)	2,400
Pot Life (Time to 3,500 cP, hr.)	1

Table 9  
Performance of New Curing Agent/LTCA Blends With 45°F Cure

	TFST (hr)	Hard Dry (hr)	MEK Resistance	60° Gloss	Amine Blush
100% NCA	>24	>48	1 day 0 3 day 1	57	slight
100% LTCA	14	18	1 day 5 3 day 5	96	none
75% NCA 25% LTCA	>24	<48	1 day 2 3 day 4	61	none
50% NCA 50% LTCA	19	22	1 day 3 3 day 4	73	none

ACKNOWLEDGEMENTS

Table 10  
Performance of New Curing  
Agent/LTCA Blends With 55°F Cure

	TFST (hr)	Hard Dry (hr)	MEK Resistance	60° Gloss	Amine Blush
100% NCA	>24	28	1 day 3 3 day 5	90	slight
100% LTCA	6	<16	1 day 5 3 day 5	105	none
75% NCA 25% LTCA	14.5	26	1 day 4 3 day 5	95	none
50% NCA 50% LTCA	8	<16	1 day 4 3 day 5	97	none

Table 11  
Performance of New Curing Agent/LTCA  
Blends With 72°F Cure

	TFST (hr)	Hard Dry (hr)	MEK Resist- ance	60° Gloss	Amine Blush
100% NCA	8	13	1 day 4 3 day 5	92	v. slight
100% LTCA	5	7	1 day 5 3 day 5	109	none
75% NCA 25% LTCA	7.5	10	1 day 4 3 day 5	100	none
50% NCA 50% LTCA	7.5	9	1 day 5 3 day 5	102	none

Thin Film Set Time = BK dry time tester stage 3

Hard Dry = ASTM D-1640

MEK Resistance Ratings

- 0 Penetration to substrate in < 50 rubs
- 1 Heavy depression in coating, no penetration to substrate
- 2 Heavy marring, obvious in depression in film
- 3 Some marring, apparent depression in film
- 4 Burnished appearance in rubbed area
- 5 No effect on surface

Amine Blush - Rated at zero induction time, after 4-day cure

60° Gloss - Measured after 4-day cure

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## REFERENCES

- (1) Rozenberg, B.A. *Adv. Polym. Sci.*, p75,113 (1986)
- (2) Moore, W.J. *Physical Chemistry, 4<sup>th</sup> Ed.*, Prentice-Hall: Englewood Cliffs, NJ, pp. 334-336 (1972)
- (3) Tanaka, Y.; Bauer, R.S. 'Curing Reactions,' in May, C.A. (Ed.), *Epoxy Resins Chemistry and Technology, 2<sup>nd</sup> Ed.*, Marcel Dekker: New York, pp. 293-304, and references therein (1988)
- (4) Burrell, H. *Official Digest*, 34 (445), 131 (1962)
- (5) Bauer, D.R. *J. Coat. Tech.*, 60 (758), 33 (1988)
- (6) a) Miller, D.R.; Macosko, C.W. *Macromolecules*, p.9, 207 (1976);  
b) Miller, D.R.; Valles, E.M.; Macosko, C.W. *Polym. Eng. Sci.*, p.19 (4), 272 (1979)
- (7) Bird, R.B.; Armstrong, R.C.; Hassager, O. *Dynamics of Polymeric Liquids*, Wiley: New York, pp. 190-194 (1977)
- (8) Lucas, P.A.; Clark, P.A.; Haney, R.J.; Kittek, M.R. *J. Prot. Coat. Lin.*, p.15 (8), 20 (1998)
- (9) Wisanrakkit, G.; Gillham, J.K. *J. Coatings Tech.*, p. 62, (783), 35 (1990)
- (10) Ancamide® 805 curing agent, Air Products and Chemicals Inc. <sup>1</sup>.
- (11) Hansen, C., 'Solubility Parameters' in Koleske, J.V.(Ed.), *Paint and Coating Testing Manual, 14<sup>th</sup> Ed.*, ASTM: Philadelphia, pp. 383-404 (1995)
- (12) Wollastocoat® 10ES, NYCO Inc.
- (13) Oxsol® 100, Oxychem Inc.
- (14) Ancamine® 2505, Air Products and Chemicals, Inc.