FINAL REPORT

TESTING OF LOW-SOLVENT AIR DRIED FORCE DRIED AND BAKED COATINGS FOR MISCELLANEOUS METAL PARTS AND PRODUCTS

CONTRACT #A5-175-32

CALCOAST ANALYTICAL LABS

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PREPARED FOR CALIFORNIA AIR RESOURCES BOARD

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DISCLAIMER

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1. Abstract:

Currently available organic coatings and a representative sampling of emerging technologies are evaluated and compared with traditionally acceptable coatings in special use categories.

New and developing polymer systems such as water based dispersions and emulsions, low solvent solution resins, single and two component or catalysed urethane isocyanate - acrylate and the like are evaluated as air dry (ambient temperature) curable or epoxy-amine force dry ($<194^{\circ}F$) coatings. High temperature baked coatings, which cure at temperatures greater than $194^{\circ}F$ are also included in this work.

Physical, compositional and exposure performance properties evaluated within the special use category are those necessary to provide information allowing comparison of low solvent and waterborne systems with existing acceptable solvent based coatings which are noncompliant with respect to Volatile Organic Compounds (VOC) content and/or Photochemically Reactive Organic Compounds (PROC) content.

The "State of the Technology" of polymer and additive development and formulation of Low Solvent and Water Borne coatings is explored.

2. Sampling Program:

During the latter part of 1986, Ron Joseph & Associates designed and instrumented a sampling program for coatings in each of nine categories such that they would contain the lowest VOC-contents commercially available. The nine categories were:

Solar Absorbant
Heat Resistant
Chemical Milling Maskant
High Gloss
Metallic
Prefabrication Architectural
Computer and Business Machines
Military Specification
General Metal

Before describing each category in detail, a few general comments will be of interest. In planning the sampling portion of this project, consideration was given to the wide range of resin technologies that can be used in each of the categories selected in this study. Therefore, sampling was not haphazard. On the contrary, the plan was to obtain as broad a range of samples as would adequately represent the resin technologies available in each category.

To ensure that coating suppliers were given a fair opportunity to supply coatings for this study, over 24 companies were contacted. They included the following:

Cardinal Industries, Triangle Paints, Dexter-Midland, O'Brien Corporation, John L. Armitage, Spraylat, Sherwin-Williams, Pratt & Lambert, Amchem Products, Ellis Company, Red Spot Paint and Varnish, Reliance Universal, Cook Paint and Varnish, PPG Industries, Hughson Lord Chemicals, Hentzen Coatings, Lilly Industrial Coatings, D.J. Simpson, 3M Corporation, Valspar, Rust-Oleum, Glidden Paints, Turco Products and AC Products.

Of these companies only 14 submitted a total of over 80 samples. Some of the samples arrived too late to be included in the study, while others were returned to the coating companies because the study could not handle this large quantity of submissions. Care was taken to retain coatings that would provide this study with as broad as possible a representation of each category.

1. Solar Absorbant:

These coatings are non-selective solar absorbants designed for high temperature service. For instance, when applied to aluminum substrates, the coating integrity and its solar absorption of 0.96 are unaffected by temperatures of up to 1000°F. Typical end uses include optical instrumentation, solar, aircraft parts and decorative application for tool and die stamped parts. They are primarily designed for non-wear applications.

Soon after commencing this task, it became evident that there was no great demand in the industry for this category of coating. While companies such as Cardinal Industries, claimed to have a "Solar Absorbant" Coating, it was not of the same quality as those demanded by the market place. Apparently, 3M coatings are the industry standards. On account of the very small quantity of such coatings being used, 3M had no plans to reformulate their products to meet the California VOC rules. VOC-contents are approximately 4 lbs./gal.

Because of their special performance characteristics and their small volume usages, end-users can qualify for the "Extreme Performance" exemptions in rules such as Bay Area Regulation 8, Rule 19, and South Coast Rule 1107. Therefore, after consultation with CARB staff, it was decided to eliminate this category from the study.

2. Heat Resistant Coatings

The two leading rules for miscellaneous metal parts and products, Rules 19 of the Bay Area Air Quality Management District (BAAQMD) and Rule 1107 of the South Coast AQMD, define such coatings as having to withstand temperatures in excess of 400°F. Both rules require VOC contents not exceeding 420 g/l for air dry and 360 g/l for bake coatings.

Heat resistant coatings are formulated with different resin systems depending on the temperature to which they will be subjected. In general, as the service temperature increases, so the resins tend to move from alkyd formulations to those containing greater amounts of silicone resins. In this study, samples were solicited for three temperature ranges:

400° - 800°F
700° - 1000°F
800° - 1500°F

Cook Paint and Varnish Company submitted two coatings. Their #518 Hi Heat Aluminum is a silicone leafing aluminum capable of withstanding temperatures of up to 1000°F, while product #100-A-899 is a 100% silicone resin, also with aluminum flake, designed for a temperature range of 500° - 800°F. Details of the other resins submitted were not available.

3. <u>Chemical Milling Maskant</u>:

Bay Area Rule 19 defines "Chemical Milling Maskant Coatings" as follows:

> Any coating which is applied to a component to protect areas when performing chemical milling, anodizing, aging, bonding, plating, etching, and/or other chemical surface operations on the component.

These coatings are currently exempt from Rule 19. Rule 1107 of the South Coast does not address this coating at all. However, both districts do have provisions in their respective aerospace rule (Rule 29 in the Bay Area and Rule 1124 in the South Coast). The former rule requires a reduction of emissions by 90 percent when such coatings are used after January 1, 1988, whereas the South Coast rule recognizes the general unavailability of low-VOC chemical milling maskant coatings, and has set a VOC standard of 1200 g/l.

It is not known how much of this coating is used in the miscellaneous metal parts industries, but clearly the major market is for aerospace applications. In soliciting samples of these coatings, it was found that one of the primary suppliers to the aerospace industry is AC Products, Inc. of Placentia, California. This company sells over fifty maskants to approximately eighty percent of the aerospace companies in the United States. According to this company there are several different etchant formulas needed to chemically mill ten or more aluminum alloys. In addition, there are a variety of magnesium, steel, stainless steel, titanium and refractory alloys that must be processed in specific etchants controlled within limited concentration ranges. Apparently, products are available with VOC contents as low as 680 g/l, while the range goes as high as 1200 g/l. According to AC Products, there is not much demand for the lower VOC products.

Because of the complexity of this technology and because these coatings are more appropriately studied in conjunction with aerospace coatings, the ARB staff agreed that this category should be dropped from the study.

4. <u>High Gloss Coatings</u>:

Both Miscellaneous metal parts rules define this category of coatings as "achieving at least 75% specular reflectance on a 60° meter when tested by ASTM Method D523". Although both rules refer to this category as "Extreme High Gloss", the 75% specular reflectance level is not particularly difficult to achieve with most resin technologies. On the other hand, gloss levels well in excess of 90% specular reflectance are more difficult to achieve in some technologies, particularly with the water-bornes air dry and force dry ($<194^{\circ}F$) resin systems. Therefore, in soliciting samples for this study, an attempt was made to obtain the highest gloss levels with the lowest VOC contents that were commercially available. Moreover, the sampling was conducted among the most common resin systems being used by the miscellaneous metal parts industry. These technologies included the following:

Acrylic-based polyurethanes used primarily by the transportation industry.

Polyester-based polyurethanes used primarily by the lighting fixture, appliance, medical instrumentation, and allied industries.

Acrylic baking enamels. Same as above.

Moisture cured, **pigmented**, single component polyurethanes. This technology is still in the process of being developed. Currently, approximately three mid-west companies are selling moisture cure polyurethanes in the extreme **low gloss** range where they are used for camouflaging purposes. However, at least two of these companies have been developing extreme high gloss coatings which are intended for the same markets as the high gloss acrylic-and polyester-polyurethanes.

Water-borne, air dry and low cure (<194^{O}F) enamels: These coatings, many of which are latexes, are intended for application to metal and plastic substrates, and are available in strictly air drying and force drying formulations. They are used in the low end of the miscellaneous metals industry, where high performance is not a requirement.

Water-borne, high bake (>194^{O}F): Unlike the previous technology, these coatings are intended solely for application to metals, and are being used in applications similar to those of the polyurethanes and high bake acrylics and polyesters.

5. Metallics:

Both rules have special provisions for metallic coatings which, in Rule 19, are defined as follows:

Metallic Topcoats: Any coating which contains more than 5 g/l (0.042 lbs/gal) of metal particles, as applied, where such metal particles are visible in the dried film.

The VOC standards for metallic coatings in both rules is 420 g/l (3.5 lbs/gal).

This category could refer equally to coatings that have a distinct appearance of metallic **aluminum**, such as are colloquially referred to as "silver paints", and those that are colored and provide a metallic sparkle. The second group of coatings are popular as automotive finishes.

Recognizing the fact that some coating facilities do not have ovens, we further differentiated this category into air drying and bake (>194^{O}F).

Therefore, samples were provided as follows:

Aluminum finish - air dry
Aluminum finish - bake
Pigmented metallic - air dry **(No sample)**
Pigmented metallic - bake
Water-reducible, pigmented metallic - bake

6. Prefabricated Architectural:

When rules 19 and 1107 were originally developed, there was an apparent need for coatings that would be used by fabricators to prime-coat architectural sub-sections prior to shipping them to construction sites. Bay Area Rule 19, provided as follows:

> **Exemption, Prefabricated Structural Components:**
> The requirements of this Rule shall not apply to the use of air-dried coatings applied during manufacture of structural components provided that such coatings comply with the limits in Rule 3 (Architectural) or Rule 4 (General Solvent and Coating Operations) of this regulation which would apply to the coating of such structures after final erection.

In other words, in the Bay Area all on-site or off-site fabricators and coaters could follow the architectural rule when coating such structures. Recently, the Bay Area staff ruled that any structures which are coated **off-site** fall into Rule 19, and therefore must comply with the limits of 340 g/l (2.8 lbs/gal) for air dry, and 275 g/l (2.3 lbs/gal) for bake coatings. This requirement holds even if the structure is architectural in nature and will receive its topcoats on site. The topcoat application, however, will be subject to the architectural rule. Therefore, in the latest revision to Rule 19, there is no special provision for the "Prefabricated Architectural" category of coatings.

The South Coast Rule 1107 still does provide special dispensation for **air dry** coatings in this category, but not for bake coatings. Air dry coatings must be at the 420 g/l (3.5 lbs/gal) limit.

Although neither rule describes the type of coating intended in this category, the coatings which are used in the prefabrication stage of a building project are usually corrosion-resistant air dry primers. Therefore, this study concentrated on sampling the most common types of primers that may be used. In fact, rather than limit the selection to primers for architectural purposes, we sampled general purpose primers so as to provide this study with more useful information.

We were not able to locate solvent-based low VOC primers, but did sample a range of water-borne primers. Formulations containing 1,1,1 trichloroethane were also not sampled due to the controversial attitude that the industry has towards this exempt solvent. There is general concern that the solvent may cause health problems to coating operators; there are concerns regarding safety, and a fear that sooner or later 1,1,1 trichloroethane will be regulated.

Deft Inc. mades **water-reducible epoxies** primers which meet the 2.8 lbs/gal limit, but are generally used in military applications. They have already been approved by the Army under specification MIL-P-53030, and by the Naval Air Systems Command under specification MIL-P-85582. We did not include either primer in this study as their performances have already been proven. Both primers are relatively widely used in California.

7. Computer and Business Machines:

The Bay Area (Silicon Valley) probably boasts the highest usage of these coatings in the nation, and Rule 19 was developed largely with this industry group in mind. Therefore it is understandable that compliant coatings, meeting the lowest VOC limits for either air dry or bake conditions are available.

An important distinction of this group of coatings is that they usually are required to have gloss levels of 18 - 22 specular reflectance on a 60° gloss meter, and that a smooth finish of the coating is usually followed by a texture finish using the same coating. Therefore, one of the tests used to qualify this group of coatings is to confirm the ability of the product to produce a range of texture patterns when applied with a conventional spray gun.

In sampling coatings for this study, we once again covered a comprehensive range of **liquid** coating technologies. While powder coatings, (emitting virtually no VOC's) are being used in this industry, they did not form part of this program.

The resin systems sampled were as follows:

High solids, two component polyester-based polyurethanes.

Water-borne air dry or force dry (<194°F): These are used primarily on plastic substrates, but are also being used on metal parts that are too large to be placed in ovens, metal castings that cannot be oven cured as a result of outgassing, or machined parts or castings that cannot be oven cured due to potential warpage.

Water-reducible high bake (>194°F): These are used primarily on metal parts. This technology is competitive with the two-component polyurethane.

Water-borne primer surfacer. These are used on castings and plastic parts where a smooth topcoat will be applied. The primer surfacer must have excellent sanding properties and must hide all substrate imperfections, such as blow holes, small dents, scratches, etc. Furthermore, the primer surfacer must be compatible with a water-reducible topcoat.

Polyurethane primer surfacer. The same function as the water-borne primer surfacer, but preferred where a polyurethane topcoat is to be applied.

8. Military Specification Coatings:

The contract had included this category of coatings and sampling commenced for a wide number of commonly used military specification coatings. However, after discussions with the Air Resources Board staff, it was decided that the category should be dropped from the study because these coatings were already being qualified by military coatings laboratories. Existing approved military coatings meeting both VOC limits and military specifications are included in this report. See appendix V.

9. General Metal Equipment:

This category is the catch-all for general purpose coatings not already covered by any of the previous industry-specific categories.

We did not include primers in this category, because they had already been included in the "Prefabrication" group of coatings.

Once again, sampling was intended to cover as wide a range of liquid resin systems as possible. Those sampled were as follows:

High solids alkyd, air or force dry

Polyurethane, single component, moisture cure. As was earlier discussed, this is a new technology, and these coatings are not yet readily available on the market, but can be expected to be introduced for general purpose use during the next few years.

Epoxy high solids. Currently they are used primarily for military applications, but can equally be used for general purpose high performance, interior exposure applications.

Polyester high solids bake, for metal furniture, lighting fixtures, metal shelving, etc.

Water-borne air dry alkyd, generally for the low end of the metal finishing market.

Epoxy water-reducible, for high performance interior applications where polyurethanes are not desired.

Autophoretic coating. This technology emits zero VOC and is based on a water soluble resin. Currently, only one company, Amchem Products, manufactures this coating, and has already established markets in the mid-west automotive market for under the hood applications. To the best of our knowledge it is not yet being used in California, but is available. The coating should be considered more as a primer than as a topcoat, and is applied in a dipping process.

3. Test Procedures:

The test procedures used in this study were derived from applicable American Societies for Testing and Materials procedures and from Federal Test Method Standards 141B (1987).

Evaluation of ease of water cleanup of waterbased coatings, application properties using conventional and airless spray equipment, brush and roller, and appearance of the dried film are subjective, qualitative tests. The rating used is typically poor, fair, good, excellent.

1. Total Non-Volatile (% wt.)	ASTM D2369
2. Specific Gravity (Lbs./Gallon)	ASTM D1475
3. Viscosity, Cps, Brookfield	ASTM D2196
4. Color, Reflectance	ASTM D1729
5. % Water (wt.)	ASTM D1364 and ASTM D3792
6. Stability 77°F	ASTM D1849
7. Stability 120°F	ASTM D1849
8. Freeze-Thaw Resistance	ASTM D2243
9. Drytime	ASTM D1640
10. Hardness	ASTM D3363
11. Block Resistance	STD 141B FTM 6216
12. Sanding Properties	STD 141B FTM 6321
13. 60° Gloss	ASTM D523
14. Yellowness Index	STD 141B 6131
15. Humidity Resistance	ASTM D2247
16. Adhesion	ASTM D3359
17. Enamel Holdout (a)	
18. H_2O Cleanup	
19. Abrasion Resistance	ASTM D4060
20. Flexibility	ASTM D1737
21. Impact Resistance	ASTM D2794
22. Appearance	
23. Application Properties	
24. Sag Resistance	STD 141 FTM 4494
25. Levelling	ASTM D2801
26. Contrast Ratio	ASTM D2805
27. Accelerated Weathering	ASTM G23, D822
28. Salt Spray Resistance	ASTM B117
29. H_2O Repellancy	ASTM D2921
30. Fungus Resistance	ASTM D3273 and ASTM D3274
31. Volatile Organic Content (VOC)	ASTM D3960, 10.2.3
32. Heat Resistance	TTP28E, para. 4.3.10
33. Water Resistance	ASTM D1647
34. G.C. analysis is for chlorinated hydrocarbons	BAAQMD vol. 3, lab 22

4. Test Protocol:

The following table represents the specific tests performed on each sample within the six (6) categories.

TABLE 2

TESTS	CATEGORY 1	2	3	4	5	6
1. Total N.V. % WT.	x	x	x	x	x	x
2. Spec. Gravity	x	x	x	x	x	x
3. Viscosity Cps	x	x	x	x	x	x
4. Color/Reflectance	x	x	x		x	
5. % Water (wt.)	x	x	x	x	x	x
6. Stability 77°F	x	x	x	x	x	x
7. Stability 120°F	x	x	x	x	x	x
8. Freeze - Thaw Res.	All H_2O Based Products					
9. Dry Time	x	x	x	x	x	x
10. Hardness	x	x	x	x	x	x
11. Block Resistance	-	-	-	-	x	x
12. Sanding Properties	-	-	-	-	-	-
13. 60° Gloss	-	x	x	x	x	x
14. Yellowness Index						x
15. Humidity Res.	x	x	x	x	x	x
16. Adhesion	x	x	x	x	x	x
17. En. Holdout (S.S.)						
18. H_2O Cleanup	All H_2O Based Products					
19. Abrasion Res.	-	x	x	x	x	x
20. Flexibility	x	x	x	x	x	x
21. Impact Res.	x	x	x	x	x	x
22. Appearance	x	x	x	x	x	x
23. App. Properties	x	x	x	x	x	x
24. Sag. Res.	x	x	x	x	x	x
25. Levelling	x	x	x	x	x	x
26. Contrast Ratio	-	x	x	x	x	x
27. Acc. Weathering	x	x	x	x	x	x
28. Salt Spray Res.		x	x	x	x	x
29. H_2O Repellance		x		x		x
30. Fungus Res.		x	x	x	x	x
31. VOC	x	x	x	x	x	x
32. Heat Resistance	x	-	-	-	-	-
33. Water Resistance	x	x	x	x	x	x
Total Tests	23	28	27	28	30	31

A. VOC:

In order to calculate VOC, certain tests must be performed including:

1. Total Non-Volatile
2. Specific Gravity
5. % Water by weight using Karl Fischer and Gas Liquid Chromatography
34. G.C. Analysis for Exempt Solvents (Chlorinated Hydrocarbons)

B. Stability:

Tests such as:

3. Viscosity - initial
6. Stability 77°F
7. Stability 120°F

monitor viscosity changes with aging of the coating in the container and provide information with respect to application properties and modes of application.

C. Water Based Products:

Water based products only are tested for:

8. Freeze thaw resistance
18. Water-cleanup of application tools

D. All Coatings:

Tests applicable to all coatings include:

9. Drytime - set to touch and dry hard
16. Adhesion - to specific use substrate
22. Appearance
23. Application Properties

E. Water Resistance:

Water resistance properties of the cured film include:

15. Humidity Resistance
28. Salt Spray Resistance
29. Water Repellancy
33. Water Immersion Resistance

F. Dried Film Properties:

Physical property tests of the dried film include:

4. Color
10. Hardness
13. 60° Gloss
19. Abrasion Resistance
20. Flexibility
21. Impact Resistance
26. Contrast Ratio - Hiding Power

G. Wet Film Properties:

24. Sag Resistance
25. Levelling

H. Other specialty tests required for specific end use include:

11. Block Resistance (adhesion of coatings when stacked)
17. Enamel Holdout
27. Accelerated U.V. Resistance (Xenon Arc Weatherometer)
30. Fungus Resistance
32. Heat Resistance

5. Test Conditions:

The following conditions relate to tests cited in the Test Protocol.

1.	Total N.V. % Wt.	$100^{\circ}C$, 2 hrs., 1 gram sample
2.	Spec. Gravity	Weight/gallon cup, $77^{\circ}F$
3.	Viscosity Cps	Brookfield RVT (spindle, speed)
4.	Color	Instrumental, Gardner Neotec colorimeter
5.	% Water	Karl Fischer, G.L.C. (a)
6.	Stability $77^{\circ}F$	5 months, 3/4 full pint
7.	Stability $120^{\circ}F$	30 days, 3/4 full pint
8.	Freeze-Thaw Res.	3 cycles, 16 hrs., $20^{\circ}F$, 8 hrs. $77^{\circ}F$
9.	Drytime	Gardner Circular Drytime Recorder
10.	Hardness	Pencil, 7 day cure, $77^{\circ}F$
11.	Block Res.	
12.	Sanding Prop.	---
13.	60° Gloss	48 hrs. dry
14.	Yellowness Index	
15.	Humidity Res.	48 hrs. cure, 48 hrs. exposure, $100^{\circ}F$, 100% R.H.
16.	Adhesion	Crosshatch, Tape
17.	Enamel Holdout	48 hrs. cure, 3 mil wet (b)
18.	H_2O Cleanup	
19.	Abrasion Res.	48 hrs. cure, 1000 gms, CS10, 1000 rev.
20.	Flexibility	Cylindrical mandrel
21.	Impact Res.	Forward
22.	Appearance	
23.	Application Prop.	Brush, roller, spray (c)
24.	Sag Res.	
25.	Levelling	
26.	Contrast Ratio	3 mil wet film
27.	Acc. Weathering	ASTM G26, Xenon Arc Weatherometer, 300 hrs.
28.	Salt Spray Res.	200 Hrs., 5% NaCl, Bonderite 1000 Panels
29.	H_2O Repellancy	7 day cure (d)
30.	Fungus Res.	16 day exposure
31.	V.O.C.	G.C. Headspace Analysis
32.	Heat Res.	TTP28 modified to include observation at 400, 800 & $1200^{\circ}F$
33.	Water Immersion Res.	Q panel, 1/2 immersed D.I. H_2O, 22 hrs.
34.	G.C. Analysis	Direct injection for chlorinated hydrocarbons

(a) Water content: G.L.C. Analysis
(b) Enamel Holdout: ratio of 60° gloss of TT-E-489 enamel over paint vs. sealed Morest chart.
(c) Application properties: includes brush, roller, spray (airless, conventional) as applicable.
(d) Water repellancy: poor - bead lasts less than 30 min.

Gas Chromatography Test Conditions

Water Content of Water Reducible Paints by Direct Injection into a Gas Chromatograph - ASTM D3792-79

A. Conditions used:

1. Column:
   a. type: PORAPAC Q
   b. length: 10'
   c. dia.: 1/8"
   d. mesh: 80/100

2. Carrier:
   a. type: Helium
   b. inlet pressure: 70 psig.
   c. flow rate: 35.0 mls/min.

3. Integrator:
   type: HP 3390A
   chart speed: 0.5 cm/min.

4. Injector Temp.: 210°C

5. Detector:
   a. type: hot wire detector
   b. temp.: 250°C
   c. current: 150 mA

6. Temp. Program:
   a. T_I: 75°C
   b. T_F: 185°C
   c. rate: 12°C/min.

B. Procedure Used:

Approximately 0.6 g paint weighed to the nearest mg was added to 0.2 g Isopropyl alcohol and 2 mls N,N Dimethyl-formamide (note: all reagents used must be Analytical Reagent grade). The above solution was placed in a headspace vial and sealed with a silicone septum. The mixture was shaken for 5 minutes and then centrifuged at 6,000 rpm for 20 minutes. The supernatant was then directly injected into the gas chromatograph using a Hamilton microlitre syringe (note: syringe should contain at least one-half of air and 2 μls of supernatant.

(μ = micro)

6. **VOC Compliance Summary and Review:**

A. VOC Compliance Levels:

The following table indicates compliance levels cited in both Bay Area Air Quality Management District (BAAQMD) Rule 19 and South Coast Air Quality Management District (SCAQMD) Rule 1107 for the coating categories evaluated in this study. The volatile organic levels (VOC) are given in grams per litre.

Category		**BAAQMD Rule 8-19** (adopted 4/1/87) (air dry/bake)	**SCAQMD Rule 1107** (adopted 6/5/87) (air dry/bake)
1	Heat Resistant	420/360	420/360
2	High Gloss	420/360	420/360
3	Metallic	420/360	420/420
4	Prefab Architectural	340/275	420/275
5	Computer/Bus. Machines	340/275	340/275
6	General Metal	340/275	340/275

B. Calculations:

Calculations for Volatile Organic Content (VOC), were made for solvent based and water reducible coatings using the following formula from ASTM D3960:

$$A = (V_2 - W)\ (Dm) \times 10$$

where A = Volatile organic content (VOC-1)
V_2 = Weight % total volatile including water
W = Weight % water
Dm = Density of coating gms/ml

For compliance evaluation purposes, the VOC content minus water (or exempt solvent) for coatings containing water or exempt solvents was calculated from VOC-1 using the following formula from ASTM D3960:

$$VOC_2 = \frac{VOC\text{-}1 \times 100}{100 - \frac{Dm}{Dw}(W)} \qquad Dw = \text{density of water}$$

We assumed Dw = 1.0 (25°C) since the factor 0.997 has a trivial effect compared to errors in density measurement.

All VOC levels reported in this work are calculated for compliance evaluation purposes as VOC 2.

VOC Compliance Review and Summary (cont'd)

C. Study Summary:

Compliance with the above BAAQMD and SCAQMD acceptable VOC levels was evaluated using the following laboratory data:

1. Specific gravity - ASTM D1475
2. Non-volatile % wt. - ASTM D2369
3. % water (wt.) - ASTM D3792 and ASTM D1364

Water content of waterbased coatings was analysed by gas chromatography primarily and crosschecked with ASTM D1364 for coatings containing lower total water levels.

Using both gas chromatography and Karl Fischer water determinations gives a ± 1.5% water content. The standard deviations for both specific gravity and total volatile content (± 0.5%) lead to significant variations in VOC level using the minus exempt solvent/water calculations (±10%).

Category		VOC Compliant	Non-compliant	Total Samples
1	Heat Resistant	1	7	8
2	High Gloss	5	3	8
3	Metallic	4	2	6
4	Prefabricated Architectural	2	7	9
5	Computer/ Business Machines	6	3	9
6	General Metal Equipment	5	5	10
	Total	23	27	50

Compliance was determined using the Bay Area compliance levels.

Category 1 - Heat Resistant - VOC Limits 420 g/l A.D./
360 g/l Bake

Sample	VOC	Comply	Resin System	Cure Method
1.1	491		silicone	2 C. (catalysed)
1.2	523		silicone	baked
1.3	522		silicone	air dry; baked
1.4	458		silicone alkyd	air dry
1.5	442		silicone alkyd	air dry
1.6	619		silicone	air dry
1.7	446		silicone alkyd	air dry
1.8	351	X	modified silicone	air dry

Total comply: 1

VOC Compliance Review and Summary (cont'd)

Category 2 - High Gloss Coatings - VOC Limit 420 g/l A.D./ 360 g/l Bake

Sample	VOC	Comply	Resin System	Cure Method
2.1	259	X	modified alkyd	1 C., bake
2.2	406	X	polyurethane acrylic	2 C., air dry
2.3	377	X	polyurethane polyester	2 C., high solids, catalysed, A.D.
2.4	441		polyurethane acrylic	2 C., air dry
2.5	356	X	water based	1 C., air dry
2.6	380	X	catalysed urethane	high solids, catalysed, A.D.
2.7	496		polyurethane acrylic	2 C., high solids catalysed, A.D.
2.9	453		silicone polyester	1 C., air dry

Total comply: 5

Category 3 - Metallic Finishes - VOC Limit 420 g/l A.D./ 360 g/l Bake

Sample	VOC	Comply	Resin System	Cure Method
3.1	432		linseed oil alkyd	air dry
3.2	477		urethane	moisture cured
3.3	413	X	polyurethane	2 C., catalysed, A.D.
3.4	327	X	---	1 C., high bake
3.5	316	X	---	1 C., low bake
3.7	258	X	---	1 C., high bake

Total comply: 4

Category 4 - Prefabricated Architectural - VOC Limit
340 g/l A.D.
275 g/l Bake

Sample	VOC	Comply	Resin System	Cure Method
4.1	408		modified acrylic latex	air dry
4.2	386		alkyd - S.B.	air dry
4.3	416		alkyd - S.B.	air dry
4.4	389		modified alkyd	air dry
~~4.5~~	~~206~~	~~X~~	~~epoxy~~	~~2 component,~~ catalysed
4.6	607		alkyd - S.B.	air dry
4.7	567		phenolic alkyd S.B.	air dry
4.8	422		acrylic latex	air dry
4.9	288	X	alkyd	high solids, air dry

Total comply: 2

Category 5 - Computer/Business Machines - VOC Limit: 340 g/l A.D./
275 g/l Bake

Sample	VOC	Comply	Resin System	Cure Method
5.2	269	X	W.R. alkyd	W.B.*, high bake
5.3	355		alkyd	W.B., air dry
5.4	220	X	alkyd	W.B., air dry
5.5	327	X	polyurethane	2 C.*, H.S.*, S.B.*,A.D.
5.7	160	X	acrylic thermoset	1 C.*, high bake
5.8	385		W.R. alkyd	1C. low bake
5.9	240	X	alkyd	1 C., W.B., high bake
5.10	420			1 C., W.B., air dry
5.12	253	X	acrylic	1 C., W.B., low bake

Total comply: 6

Category 6 - General Metal Equipment - VOC Limit 340 g/l A.D./
275 g/l Bake

Sample	VOC	Comply	Resin System	Cure Method
6.1	198	X	epoxy	2 component catalysed
6.2	65	X	epoxy	2 component catalysed
6.3	424		epoxy	2 component catalysed
6.4	251	X	W.B. alkyd	1 C., W.B., high bake
~~6.5~~	~~336~~		~~alkyd~~	~~1 C., S.B., H.S, H.B.~~
6.6	406		alkyd	Water reducible, air dry
6.7	302	X	epoxy	2 C., water borne, catalysed
6.8	357		urethane	1 C., moisture cured
6.11	343		modified alkyd	high solids, air dry
6.13	111	X	epoxy - polyamide	2 component, catalysed

Total comply: 5

* W.B. - water based
S.B. - solvent based
H.S. - high solids
H.B. - high bake
1 C. - 1 component
2 C. - 2 component

7. Review of Performance Properties - Ranking

The coatings evaluated were ranked according to level of achievement in performance properties. Weighting criteria was developed from both the ultimate function and definition of the coating.

Values assigned to performance properties (0 poor, 10 excellent) were based on previous evaluations of coatings which are commercially available and acceptable but not necessarily VOC compliant.

Weighting factors are based on from seven to nine characteristics and the weighting value predicated on ultimate coating use.

W.F. = Weighting Factor

Category 1 - Heat Resistant

VOC Limit: 420 g/l A.D./360 Bake

	W.F.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1. Heat Resistance	40	35	40	40	0	0	0	30	0
2. Application Prop.	10	10	9	10	8	5	10	8	10
3. Accelerated U.V.	10	7	7	9	10	5	8	10	9
4. Flex/Impact	10	10	5	0	10	0	5	6	5
5. Humidity Res.	10	0	10	0	10	0	10	10	0
6. Stability	10	10	8	5	10	10	10	10	10
7. Water Res.	10	8	8	10	10	0	8	9	5
Total	100	80	87	74	58	20	51	83	39
VOC	---	491	523	522	458	442	619	446	351*

* = complies

Category 2 - High Gloss

W.F. = Weighting Factor

VOC Limit: 420 g/l A.D./ 360 Bake

	W.F.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1. Gloss	35	35	35	35	35	35	35	35	35
2. Application Prop.	15	15	12	15	15	15	15	15	15
3. Stability	10	5	5	10	5	9	0	10	10
4. Impact/Flex.	10	10	5	10	10	10	10	5	10
5. Humidity Res.	10	6	10	10	10	10	0	10	10
6. U.V. Res.	10	6	8	8	8	8	8	8	8
7. Salt Spray Res.	10	8	10	8	10	9	0	10	7
Total	100	85	85	96	93	96	68	93	95
VOC	--	259*	406*	377*	441	356*	380*	496	453

* = complies

Category 3 - Metallic Finishes

W.F. = Weighting Factor

VOC Limit: 420 g/l A.D./ 360 Bake

	W.F.	1	2	3	4	5	7
1. Appearance	20	5	20	20	20	20	20
~~2. Stability~~	~~10~~	~~0~~	~~8~~	~~8~~	~~5~~	~~0~~	~~8~~
3. Application Prop.	10	5	10	8	8	10	8
4. Flex/Impact	10	0	5	10	10	8	5
5. Adhesion	10	10	10	10	10	10	10
6. Abrasion Res.	10	0	10	10	10	8	10
7. Water Res.	10	7	10	10	10	5	10
8. Humidity Res.	10	8	8	10	10	8	10
9. Hardness	10	10	5	10	10	10	10
Total	100	45	86	96	93	79	91
V.O.C.	---	432	477	413*	327*	316*	258*

* = complies

Category 4 - Prefab Architectural Coatings

W.F. = Weighting Factor

VOC Limit 340 g/l A.D./275 Bake

	W.F.	1	2	3	4	5	6	7	8	9
1. Abrasion Res.	10	3	0	5	3	10	5	3	3	3
2. U.V. Res.	10	0	8	3	5	7	3	5	0	5
3. Flex./Impact	10	8	7	10	10	10	5	3	9	0
4. App. Prop.	10	5	8	8	10	10	8	3	8	8
5. Stability	10	8	5	7	0	5	5	5	10	10
6. Humidity Res.	10	0	0	0	8	10	0	0	9	3
7. Salt Spray Res.	20	0	16	14	8	4	16	8	0	14
8. Water Res.	20	0	16	0	6	20	16	16	6	16
Total	100	44	60	47	63	76	62	51	62	59
VOC	---	408	386	416	389	206*	607	567	422	288*

* = complies

Category 5 - Computer/Business Machines

W.F. = Weighting Factor

VOC Limit 340 g/l A.D./275 g/l Bake

	W.F.	2	3	4	5	7	8	9	10	12
1. Appearance	20	10	10	20	15	20	20	10	20	5
2. Stability	10	10	0	0	0	10	5	0	0	0
3. Abrasion Res.	10	6	3	4	5	10	7	10	8	0
4. Humidity Res.	10	0	0	10	10	10	10	0	5	0
5. Water Res.	10	0	0	0	10	10	0	0	0	0
6. Flexibility	10	10	10	10	10	10	5	10	8	0
7. Impact	10	10	10	5	10	10	5	10	5	0
8. App. Prop.	10	6	10	9	10	10	10	10	10	5
9. Adhesion	10	10	10	8	10	10	6	10	0	4
Total	100	62	53	66	80	100	68	60	56	14
VOC		269*	355	220*	327*	160*	385	240*	420	253*

* = complies

Category 6 - General Metal Equipment

W.F. = Weighting Factor

VOC Limit 340 g/l A.D./275 g/l Bake

	W.F.	1	2	3	4	5	6	7	8	11	13
1. Salt spray	20	15	20	20	20	10	5	10	10	20	20
2. Humidity Res.	10	10	10	10	10	10	3	5	3	10	10
3. Water Res.	10	10	10	8	10	10	5	0	10	10	10
4. U.V. Res.	10	8	8	10	8	8	3	4	6	10	10
5. Appearance	10	10	10	10	10	10	10	10	10	10	8
6. App. Prop.	10	8	6	10	10	10	10	10	8	10	0
7. Stability	10	10	10	8	8	4	0	10	4	5	0
8. Impact/ Flexibility	10	0	0	8	8	10	5	10	10	5	5
9. Adhesion	10	10	10	10	10	10	10	10	0	8	10
Total	100	81	84	94	94	82	51	69	61	88	73
VOC	---	198*	65*	424	251*	336	406	302*	357	343	111*

* = complies

8. Discussion of Test Results:

A summary of each coating resin or polymer type, taken from the literature accompanying the coating samples is given in section 8.1.

A separate section 8.2 lists coatings evaluated in this study with respect to liquid phase (water, organic solvent) and curing mechanism, i.e., air dry, baked or catalysed.

Since the summary is redundant in that a water based two component epoxy or a water based high bake coating will appear in two categories or a high solids two component water based epoxy will appear in three categories, the categorization was made to indicate only technologies being explored by the coating manufacturing industry to produce VOC Compliant coatings.

Apart from the numerical values assigned to rating criteria in section 7, Review of Performance Properties, the coatings in this discussion are also rated as poor, fair, good or excellent in this section based on overall evaluation of performance properties.

A. Category 1: Heat Resistant Coatings

All samples tested for heat resistance were either pure silicone resins or a copolymer of polyester and silicone resins.

The maximum temperature used for heat resistance evaluation was 1200^{o}F. Evaluation of the modified silicone resin coatings was made at 440 and 800^{o}F. All of the coatings tested in this category were air dried; sample 1.1 was catalysed and the pure silicone resin coatings required a heat cure (samples #1.2,1.3,1.6). A total of 40% of the assigned weighting was given for high heat resistance, with 10% given to application properties, U.V. resistance, flexibility/impact resistance, humidity resistance, stability and water resistance.

Only one VOC compliant coating, sample 1.8, a modified silicone, high solids solvent type was submitted for testing. Failure of the high temperature test and of humidity resistance and water resistance gave this coating an overall poor rating (39) and the lowest rating in category one. The lowest VOC coating from our sampling provides acceptable performance properties appears to be around 520 gms/litre.

B. Category 2: High Gloss Coatings

The samples evaluated in this category included a variety of curing mechanisms and resin types. The minimum initial gloss value given in the definition of coatings in the High Gloss category i.e., 75 using a 60^{o} Glossmeter was exceeded by all samples. The total weighting factor given to gloss compliance was 35%, with 15% to application properties, 10% to each of stability, impact/flexibility, humidity resistance, ultra violet resistance and salt spray resistance. The exposure weighting was used to evaluate gloss retention and to rate the coatings for exterior durability.

The VOC compliant coatings were rated as follows:

Sample 2.1 - a water based single component modified alkyd, high bake (15 minutes at 350^{o}F) coating was rated fair to poor in both ultra violet resistance and humidity resistance. The coating also tended to settle hard and lose viscosity (208 to 164 cps) and therefore was rated fair - poor in stability. A large gloss reduction (95 initial to 49 final) after ultra violet exposure and the existence of blisters on humidity exposure led to the poor exposure ratings. The overall rating was good (85).

Sample 2.2 - a high solids, solvent based catalysed polyurethane acrylic was given a fair rating (85) due to poor package stability and marginal impact and flexibility resistance.

Sample 2.3 - a two component high solids polyurethane polyester was rated excellent (96) good - excellent in all tests performed and was rated highest of all submittals VOC Compliant and Non Compliant.

Sample 2.5 - a single component air dried water based coating (40% solids) with a VOC of 356 gms/litre showed generally excellent performance properties with an overall rating of excellent (96). Sample 2.5 was rated highest of the VOC Compliant coatings and highest of total submittals in category 2.

Sample 2.6, a high solids catalysed urethane failed water resistance, humidity resistance and showed poor package stability and was therefore given a poor overall rating (68).

C. Category 3 - Metallic Finishes

The products evaluated in the metallic finish category included both air dried and baked alkyd resin types, a moisture cured and two component ambient temperature and polyurethane and one water based low bake finish.

The major weighting factor was 20% for appearance. The other evaluation parameters given 10% each included application properties, flexibility and impact, adhesion, abrasion resistance, water resistance, humidity resistance, and hardness.

The VOC compliant coatings were rated as follows:

Sample 3.3, a two component polyurethane was rated excellent overall with the highest rating (96) for the coatings evlauated. VOC level 413 g/l.

Sample 3.4 was ranked second overall of the six submittals with a ranking of 93. The 120^{o} stability was poor and a tendency to settle and skin was noted. The sample is a high solids, high bake, single component, solvent based coating. VOC level 327 g/l.

Sample 3.5 was ranked fair with an overall rating of 79. 120^{o}F over stability failed (gelled) and water resistance was rated poor.

Sample 3.7 was ranked third overall of the six submittals with a rating of 91. The sample is a high bake, single component high solids solvent based coating. VOC level 258 g/l.

Category 4 - Prefabricated Architectural Coatings

The coatings evaluated in this category included three high solids alkyd based products, two air dried and one low bake cured. The balance of the coatings are alkyd and phenolic alkyd noncompliant solvent based coatings, two acrylic emulsion coatings and a two component water based epoxy air dried coating.

The major weighting factor was 20% for appearance with the balance of evaluation parameters with 10% each including abrasion resistance, ultra violet (accelerated weathering) resistance, flexibility and impact resistance, salt spray resistance and water resistance.

The VOC Compliant coatings were rated as follows:

Sample 4.5 - a two component water dispersible epoxy was given the highest rating (84) but showed poor salt spray resistance and only fair ultra violet resistance. (VOC (64) level 206 g/l)

Sample 4.9 - was ranked second overall (64) but failed flexibility and impact tests (1/2" cylindrical mandrel and 12 inch lbs) and has both poor abrasion resistance and humidity resistance.

All of the coatings evaluated were air dried materials.

Category 5 - Computer and Business Machines

Products evaluated in this category included water based air dried, low bake and high bake, alkyd and acrylic emulsion coatings, two component polyurethane high solids, and single component waterbased high and low bake alkyd and acrylic coatings.

The weighting factors comprised of appearance 20% and 10% for each of stability, abrasion resistance, humidity resistance, water resistance, flexibility, impact, application properties and adhesion.

All of the coatings evaluated in this category were VOC Compliant with the limit of 420 g/l. Bay area 340 g/l for A.D.; 275 g/l for Bake; South coast 420/275.

The VOC Compliant coatings were rated as follows:

Sample 5.2 - a water based low bake, alkyd type was rated fair (62) but failed both humidity and water resistance.

Sample 5.4 - a water based air dried alkyd was rated fair (66) failing stability and water resistance and impact resistance.

Sample 5.5 - a two component polyurethane high solids coating was rated good (80) but failed stability and abrasion resistance tests. VOC level 327 g/l.

Sample 5.7 - was rated excellent and best of the coatings evaluated. This material is a single component high bake acrylic thermosetting coating, water based, with a VOC of 160 gms/litre.

Sample 5.9 - a single component high bake water reducible alkyd coating was rated fair (60) failing 120^{o} stability, humidity resistance, and water resistance.

Sample 5.12 - a single component, acrylic water based, low bake coating was rated poor (14) failing practically all tests.

Category 6 - General Metal Equipment (topcoats)

The products evaluated in General Metal Equipment Coatings included two component epoxy solvent based and high solids, a two component water based epoxy; high solids alkyd water and solvent based coatings; a moisture cured urethane and a water based high bake alkyd.

Salt Spray resistance was given the major weighting factor (20%) with 10% allocated to humidity resistance, water resistance, ultra violet resistance (accelerated weathering), appearance, application properties, stability, impact, flexibility and adhesion to metal.

A total of ten (10) coatings were evaluated in this category and all coatings complied with a VOC level of 420 g/l.

The compliant coatings were ranked as follows:

Sample 6.1 - a high solids, two component solvent based epoxy was rated good (81) failing impact/flexibility and with fair - good application properties and ultra violet resistance.

Sample 6.2 - another high solids, two component solvent based epoxy was rated good (84) fails impact/flexiblity and requires 30% reduction with 111 trichloroethane for spray application.

Sample 6.4 - a single component water based high bake coating was rated excellent (94) and equivelant to sample 6-3, a high solids two component epoxy.

Sample 6.7 - was rated fair (69). This product is a two component water based epoxy. Failures included water resistance, humidity and ultra violet resistance.

Sample 6.13 - a two component high solids epoxy-polyamide was rated fair - good but failed. 120^{o}F stability, flexibility and was extremely high in viscosity requiring a 40% reduction with 111 trichloroethane for spray application.

8.1 Summary of Coating Resin/Polymer Types and curing mechanism

Category 1 - Heat Resistant

1.1 silicone - temperatures between 500 - 800°F catalysed
1.2 silicone - temperatures up to 1,000°F, A.D. heat cured
1.3 silicone - temperatures up to 1,200°F, A.D. heat cured
~~1.4 silicone alkyd: 400°F - 800°, A.D~~
1.5 silicone alkyd - no temperature information provided A.D.
1.6 silicone - temperatures up to 1,000°F, A.D. and bake
1.7 silicone alkyd: 400°F - 800°F, A.D.
1.8 modified silicone: 400°F - 800°F, A.D.

Category 2 - High Gloss Coatings

2.1 single component - high bake (10/325), modified alkyd, water based
2.2 two component polyurethane acrylic, solvent based, high solids
2.3 two component polyurethane polyester, solvent based, high solids
2.4 two component polyurethane acrylic, solvent based with 111-TCA 2.5 single component water based
2.6 single or catalysed urethane, high solids, solvent based
2.7 two component polyurethane acrylic, high solids, solvent based
2.9 single component - silicone polyester

Category 3 - Metallics

3.1 linseed oil alkyd
3.2 moisture cured urethane
3.3 two component polyurethane
3.4 single component - hi bake (10/350) high solids, solvent base/no info.
3.5 single component - water based - low bake (30/150) no info.
3.7 single component - solvent based high solids - high bake (10/350)

Note: when coatings are force cured, the conditions of curing are indicated in parenthesis (A/B):

A = curetime
B = cure temperature

Category 4 - Prefabricated Architectural

4.1 modified acrylic latex
4.2 alkyd - solvent base, high solids, air dry
4.3 alkyd - solvent base, high solids, air dry
4.4 modified alkyd - water dispersible
4.5 two component - water thinned epoxy
4.6 alkyd solvent based
4.7 phenolic alkyd - solvent based
4.8 acrylic latex water borne
4.9 alkyd - hi solids, low bake

Category 5 - Computer/Business Machines

5.2 water based - low bake, W.R. alkyd, (30/150)
5.3 water based - air dry, alkyd
5.4 water based - air dry, alkyd
5.5 two component, polyurethane, high solids, S.B.
5.7 single comp., high bake, (45/275) acrylic thermoset, W.B.
5.8 single comp., low bake W.B.
5.9 single comp., high bake, water red., (30/300) alkyd
5.10 single comp., low bake, W.B., (30/150)
5.12 single comp., acrylic, W.B., low bake, (150/30)

Category 6 - General Metal Equipment (topcoats)

6.1 two component epoxy, high solids
6.2 two component epoxy, high solids
6.3 two component epoxy, high solids
6.4 single component, water based, hi bake (10/350)
6.5 single component, solvent based - hi solids, hi bake (10/350)
6.6 alkyd - water reducible, air dry
6.7 two component, water borne epoxy
6.8 urethane - single component moisture cured, high solids
6.11 modified alkyd - hi solids
6.13 two component epoxy - polyamide, high solids

8.2 Summary of Coatings Samples - Curing Method and Liquid Phase Type

	Water Based Coatings	Two Component Coatings	High Solids Coatings	Force Dry and Baked Coatings
Category 1 -	none	1.1	1.7 1.8	1.2 1.3 1.6
Category 2 -	2.1 2.5	2.1 2.3 2.4 2.7	2.2 2.3 2.6	2.1
Category 3 -	3.5	3.3	3.3 3.4 3.7	3.4 3.5 3.7
Category 4 -	4.1 4.4 4.8	4.5	4.9	4.9
Category 5 -	5.2 5.3 5.4 5.7 5.8 5.9 5.10 5.12	5.5 5.11	5.5 5.12	5.2 5.7 5.9 5.10 5.12
Category 6 -	6.4 6.6	6.1 6.2 6.3 6.13	6.1 6.2 6.3 6.5 6.8 6.11 6.13	6.4 6.5
Totals	16	13	18	15

High solids coatings: % N.V. by wt. 60%

9. SUMMARY AND CONCLUSIONS

Although some portion of thirty-two (32) criteria were tested for each sample (see Test Protocol page 16) some criteria are more specific to rating a coating for its efficacy within a category. For the purpose of this evaluation, certain test results are assigned weighting factors to highlight their usefulness as prime criteria in arriving at a numerical rating for each of the samples tested. In our experience the prime criteria chosen are the most useful within the framework of the California Air Resources Board Definitions (App.-1). The ratings are tabulated in the Review of Performance Properties (pg. 25).

A. Category 1: Heat Resistant Coatings:

A total of eight coatings were evaluated in this category. One coating was VOC compliant. Sample 1.8 with a VOC of 351 g/l meets the requirements of 420 g/l air dried and 360 g/l baked. However, this coating, described as a silicone modified alkyd with a working temperature range of 400 - 800°F, failed at 800°F and was given the second lowest overall rating of all samples submitted.

Since the coatings in this category were divided into functional temperature ranges, the heat resistance procedure specified in Federal Specification TTP28E, para. 4.3.10, which requires a gradual temperature increase to a maximum of 1200°F over 104 hours, was modified and the samples were observed after 400°F, 800°F and 1200°F steps and rated accordingly.

Samples 1,4,5,7 and 8 were described as silicone alkyd or modified silicones with upper temperature limits generally of 800°F.

There is apparently no correlation between the VOC levels and overall performance of the samples evaluated except that the coatings with the two lowest VOC values had the lowest overall ratings.

Sample 7 with a VOC level of 446 is close to the current 420 g/l requirement for air dried coatings and shows generally good performance properties. High temperature performance was fair-good since a color change occurred. In general, high heat coatings require pigmentation with ceramic frits than conventional metal oxides to prevent color change at elevated temperatures.

Sample	**Rating**	**VOC**
1.2	87	523
1.7	83	446
1.1	80	491
1.3	74	522
1.4	58	458
1.6	51	619
1.8	39	351
1.5	20	442

The lowest VOC level for acceptable high temperature performance for the samples evaluated is 446 g/l.

It is concluded that for intermediate range continuous heat resistance (400-800^{O}F), which requires a silicone modified organic vehicle, the VOC compliance level of 420 g/l is currently being closely met by the coatings industry. Sample 1.7, a solvent based high solids coating achieves close to VOC compliance and a good overall performance rating.

For coatings designed for high temperature resistance >(1000^{O}F) the pure silicone aluminum or ceramic frit pigmented coatings appear, from the submittals evaluated, to require a higher VOC level. Samples 1.2 (VOC 523) and 1.3 (VOC 522) which were rated excellent (87) and good (74) respectively indicate that the current industry technology cannot comply with assigned VOC compliance level.

B. Category 2: High Gloss Coatings

A total of eight coatings were evaluated in this category. Five coatings were VOC compliant with the established 420 g/l limit. Sample 2.1 is single component, high bake, water based coating; sample 2.2 is a two component polyurethane acrylic, solvent based, high solids coating; sample 2.3 is a two component polyurethane with high solids content; sample 2.5 is a single component water based coating; sample 2.6 is a high solids content moisture cured urethane.

Samples 2.3 and 2.5 were rated as excellent (96) both among the submittals and compared to standard high gloss non-compliant coatings. Both systems are ambient temperature cured.

Sample 2.5 failed fungus resistance but since fungus resistance was not used in the final ranking and since fungus resistance is an easily remedied deficiency, no devaluation of the coating was effected.

It is concluded that VOC compliant gloss coatings are currently being marketed by the Coatings Manufacturing Industry in several technologies including single component air dried water based, high solids two component solvent based urethanes, and water based alkyd high bake coatings.

The level of VOC for coatings which meet the performance criteria of traditional coatings in the high gloss category evaluated in this study is 360 g/l.

C. Category 3: Metallic Coatings

A total of six coatings were evaluated in the metallic coatings category. Four of the coatings were VOC compliant with the 420 g/l requirement.

The compliant coatings included a two component polyurethane (3.3) with a VOC of 413 g/l, and three baked or force dry coatings; two solvent based high solids types samples 3.4 and 3.7 and a water dispersible alkyd sample (3.5) with a VOC of 316 g/l.

Sample 3.3 was rated excellent (96) in all performance tests and was ranked best coating among VOC compliant and non-compliant submittals.

In general for the metallic coatings category, the VOC compliant coatings outperformed the non-compliant coatings. The single component water based low bake coating (sample 3.5) was unstable and generally inferior to the solvent based two component or high solids coatings 3.3, 3.4 and 3.7 which were rated equal.

It is concluded that metallic finishes of both two component and high solids types can meet the VOC requirement of 420 g/l and perform successfully compared to conventional non VOC compliant metallic coatings.

D. Category 4: Prefabricated Architectural Coatings

A total of nine (9) coatings were tested of which two coatings, samples 4.5 and 4.9 were VOC compliant with the 340 g/l air dried and 275 g/l baked coating limits.

The VOC compliant coatings included a two component water thinned epoxy (4.5) and a high solids alkyd, force dried coating (4.9).

Sample 4.5 with a VOC of 206 g/l (mixed) was rated good overall but failed salt spray resistance. All of the samples, compliant and non-compliant in this category failed totally at least one of the performance tests and therefore, with the exception of sample 4.5, were all rated fair-poor.

Since prefabricated architectural metal structures may be in some cases too large to coat with force dried or baked coatings, it is reasonable that a catalysed or air dried coating system would be generally preferable.

It is concluded from the submittals evaluated that two component VOC compliant systems offer an alternative to conventional non-compliant coatings in this category.

E. Category 5: Computer and Business Machines

A total of nine coatings were evaluated with six coatings being compliant with the VOC limit of Bay Area 340 g/l A.D./275 bake. Sample 5.7 a water based single component, high baked (10 minutes at 350°F) thermosetting acrylic which gave the best performance values and also was lowest of all submittals in VOC level (160 g/l).

All other samples evaluated in this category failed totally (rating zero) at least one of the performance tests.

Only one other sample, 5.5 a two component polyurethane high solids coating was rated good but failed stability tests. All remaining samples were rated poor to fair.

It is concluded that the submittals evaluated constitute the current marketed varieties of VOC compliant coatings and that none of the air dried or low bake coatings have water or humidity resistance and many are unstable to storage.

The outstanding coating requires high bake cure and therefore is limited to metal substrata.

F. Cateogry 6: General Metal Equipment

A total of ten samples were evaluated in this category with five samples being VOC compliant with the limit of 340 g/l A.D./275 bake.

Two coatings 6.3 a two component high solids epoxy and 6.4 a single component water based high bake paint gave overall best performance values (94) with good-excellent ratings for all performance tests used in the ranking process. Sample 6.3 however showed excessive yellowing when tested under Federal Standard 141B, Test method 6131.

The water based coating, 6.4 gave poor abrasion resistance and marginal impact resistance (37 in. lbs.) and a gloss reduction from 92 to 65 after accelerated weathering exposure.

Sample 6.11 a high solids modified alkyd with VOC of 343 was rated as good-excellent (88) but showed poor impact resistance (17.5 in. lbs.). Water resistance and salt spray properties for the high solids coating were rated good.

It is concluded that a variety of technologies including two component epoxies, high solids alkyds and water based high bake coatings are currently being manufactured which meet the current VOC limit of 340 g/l A.D./275 bake for the General Metal Equipment Category.

10. Recommendations:

A. Category 1 - Heat Resistant Coatings

The moderate range heat resistant coatings (400 - 800°F), both pigmented with aluminum flakes and heat resistant pigments with a modified silicone vehicle system are currently being manufactured at levels close to the 420 g/l VOC limit. The 420 g/l limit is therefore reasonable and tenable for coatings manufacturers.

The upper ranges of heat resistance (>1000°F) appears to require pure silicone resins which, from our sampling and evaluation have VOC levels in the range of 520 g/l.

We recommend that the two temperature functional ranges be separately identified in terms of VOC limits.

B. Category 2 - High Gloss Coatings

The requirements for performance in this category are poorly described in the CARB definition. However, a testing program including both exterior (U.V.) durability and water resistance was implemented to provide for reasonable coating integrity aside from merely high specular gloss.

In our evaluation both a two component polyurethane-acryate and a single component water based ambient cured coating rated excellent overall and are comparable to existing industry standards.

The VOC levels of the highest rated compliant coatings was approximately 360 g/l.

It is therefore recommended that the 420 g/l limit be maintained.

C. Category 3 - Metallic Finishes

VOC Compliant coatings evaluated in the Metallic finishes category out performed the noncompliant coatings. Both a two component polyurethane and a high solids high bake coating were rated excellent in performance tests. The VOC level of the highest rated compliant coating was 413 g/l. It is recommended that the 420 g/l VOC limit be maintained since there exist currently marketed coatings meeting the requirements of performance criteria for metallic finishes.

D. Category 4 - Prefabricated Architectural Coatings

Since only two of a total nine coatings evaluated in this category were VOC Compliant, a limited amount of information is available with which to make recommendations. All of the samples evaluated failed one or more of the performance tests. The highest ranked coating, a two component water dispersible epoxy was rated only fair. The air dried VOC limit is currently 340 g/l and from our sampling, no products exist on the market which will adequately protect prefabricated metal at the 340 g/l VOC level.

E. Category 5 - Computer and Business Machines

Six of the nine coatings tested on this category were VOC Compliant. All samples failed at least one performance test in the testing protocol. The highest ranked air dried VOC Compliant coating (VOC = 327 g/l) was given a rating of 80 but failed stability and abrasion resistance tests.

Only one submittal, a high bake water based thermosetting coating (VOC 160) was rated excellent, but due to the high temperature cure, must be relegated to use on metal only.

F. Category 6 - General Metal Equipment

A total of ten coatings were evaluated and five were VOC Compliant. The highest rated compliant coating, a high bake single component water based coating (VOC 251 g/l) was good to excellent in all performance tests in the testing protocol.

Two catalysed epoxy (high solids) coatings were rated as good (VOC 198 & 65). The current 340 g/l A.D. and 275 g/l bake limit is reasonable in the light of the many technologies providing VOC Compliant or near compliant coatings for this category.