Selecting Low VOC Waterborne Coatings in the '90s

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This paper focuses on a comprehensive range of waterborne coating technologies, which include water reducible, dispersion and latex formulations. Tables which list the advantages and disadvantages of each of the resin systems will be a useful guide to those who need to select a VOC compliant coating.

Metal fabricators and coating users located in areas which are considered to be in nonattainment with the ozone standard, have already addressed the problems of selecting VOC compliant coatings. However, the New Clean Air Act amendments of 1990 have more clearly defined when an area is in attainment with the standard. In fact, the implementation of VOC regulations for surface coatings will depend on whether an area has been designated extreme (only Los Angeles-Anaheim-Riverside), severe, serious, moderate or marginal. Consequently, thousands of fabricators and other coating users who have not previously been affected by the VOC regulations, will soon be searching for low VOC coatings. The predominant question people will need to resolve is whether to convert to low VOC solvent based or waterborne coating systems.

Numerous papers have been published extolling both types of system. Indeed, since the mid 1980s high quality compliant coatings have been available to meet even the stringent requirements of California and other state rules.

This paper is devoted solely to compliant *waterborne* coatings which are applied by dip, flow, or one of the many types of spray equipment commonly used in coating facilities. The paper does not claim that waterborne coatings are better than their solvent based cousins, or vice versa. On the contrary, both types of systems should be carefully considered before making the final selection.

Before discussing the various waterborne resin systems, it must be pointed out that most VOC regulations limit the VOC content of a coating in terms of pounds per gallon or grams per liter, *less water*, and less exempt solvent. Exempt solvent containing coatings are not discussed in this paper, therefore only the *less water* terminology will be explained.

One gallon of a waterborne coating (water reducible, water dispersible or latex) contains many ingredients; specifically the resin, or binder, pigments, extender pigments, coalescing agents, a small quantity of cosolvents and usually a fairly substantial amount of water. The volatile portion of the coating comprises the cosolvents and water. In a one gallon can, the cosolvents, which are considered to be the VOCs, may accoun. for less than 1.0 lb. In other words, the VOC content of the coating may only be 1.0 lb/gal. The VOC regulations, however, require that the VOC content of the coating be calculated as if no water were in the coating. Depending on the coating formulation the VOC content, *less water* may be considerably higher, such as 2.0 lbs/gal or more.

In this paper all references to VOC content automatically assume the *less water* values. Therefore, when it is

Table I. Water Reducible, Alkyds & Modified Alkyds Air/Force Drying < 194°F (90°C)

Advantages	*Disadvantages*
VOCs generally below 2.0 lbs/gal (240 g/L).	Generally, poorer chemical resistances, compared with 2-part polyurethanes or baking water reducibles.
For use on steel, aluminum and plastics.	Three-step equipment cleanup; water, solvent, water.
One-component material with no pot life limitations, and can be touched up and repaired with itself.	Does not meet standards for "high" performance in industry, such as heavy-duty maintenance, aerospace, appliance, automotive.
Relatively easy cleanup which comprises flushing hoses with water, then solvent, then water.	More sensitive to substrate cleanliness than most solvent systems.
Low curing temperatures; ambient air dry less than 1 hour, or force dry at 150°F (65°C) for 10-20 mins.	Requires greater learning curve with regard to viscosity management than other compliant coatings.
Can be spray applied with standard equipment, but may not be compatible with airless and air assisted airless spray guns.	Generally, primers do not have as good a salt spray resistance as conventional solvent based counterparts.
Ideal as dipping primers and enamels, and excellent for general purpose primers and topcoats.	In high humidity areas, the coating must be force dried, or high velocity air must be blown over the part to quickly evaporate the water from the film.
Available in a wide range of color and gloss levels, and can be textured.	
Low fire hazard, and toxicity less than solvent-based counterparts.	
Lower costs for reducing solvents and cleanup than solvent-based counterparts.	
Exterior durability is very good.	
Chemical and solvent resistance are fair to good, but cannot compete with baked or two-component coatings.	

stated that a coating technology is commercially available with a VOC content of, say, 2.3 lbs/gal, it can be assumed that implies *less water*.

For those who are not familiar with EPA's differentiation between air/force dry coatings and those which cure by baking, a few words of clarification are in order. The EPA has defined air/force dried coatings as those which dry or cure below these temperatures, and many rules establish special VOC limits for this category. In contrast, coatings which cure above 194°F are often regulated as "baked" coatings for which other VOC limits are established. Mostly the limits for air/force dry category are higher than for the baked.

Probably the most common waterborne coatings, used for application to metals, are air or force dried at temperatures below 194°F (90°C). A wide range of coating formulations fall into this broad category. The most commonly available technologies are water reducible alkyds and modified alkyds, acrylic latexes and acrylic epoxy hybrids. Often, the consumer is unaware which of these technologies he/she is purchasing, as the coatings are frequently sold as generic "waterborne" products. A brief descriptive overview of the basic differences follows, and tables are provided which specifically highlight the most notable advantages and disadvantages of each resin system.

As a generic group, water reducible formulations, dispersions and latexes are ideal for companies which need to get into compliance with VOC regulations, yet do not require the coatings to have sophisticated properties.

As a group, the waterbornes tend to have VOC contents well below 2.0 lbs/gal, less water, and some are even below 1.0 lb/gal (120 g/L). Moreover they are readily available in a wide range of colors and gloss levels.

Generally they exhibit good performance properties, but are probably not as durable or chemical and solvent resistant as two-component polyurethanes, epoxies, or baked finishes.

You would consider them for applications such as dipping primers and topcoats, general purpose shop primers and spray applied enamels. Typical end uses include steel roof trusses, steel building support structures, farm implements (not combines or tractors), electrical cabinets, boxes, frames, fence posts, and similar "general metal" products.

Table II. Acrylic Latex Air/Force Dry < 194°F (90°C)

Advantages	*Disadvantages*
Very low VOC contents, often less than 1.5 lbs/gal (240 g/L), *less water.*	If coatings are dried in low temperature and/or high humidity environments poor films may form, leading to degraded physical and chemical properties.
Single package coatings, with unlimited pot life as long as they are in covered containers.	Must be applied over exceptionally clean, oil and grease-free surfaces.
Air dry rapidly when relative humidity is low.	Typical problems of improper surface preparation or mixing can include edge pull, poor substrate wetting and cratering.
Excellent resistance to sunlight, demonstrated by retention of gloss, color and flexibility over long periods of exposure.	Unprimed or poorly primed ferrous metals will produce severe flash rusting with most latex paints.
Generally, available in a wide range of colors and all but very high gloss levels.	Film remains thermoplastic and soluble in any solvent that would dissolve the basic polymer.
Adhere to most clean surfaces and to most industrial primers.	Latex paints contain appreciable quantities of water soluble, nonvolatile materials, such as thickeners, surfactant and other additives that remain in the dried film. On exposure, these leach out and leave the film less continuous and more permeable.
Since water is used for thinning and clean up, costs are minimized.	Splashes and spills must quickly be cleaned up with water before the coating dries. Once dry, solvents are required for clean up.
Low flammability, therefore potential to reduce insurance costs and improve better working conditions.	Equipment clean up often requires three steps: water, solvent, water.
May be applied with most conventional spray equipment, but may not be compatible with airless or air assisted airless spray guns.	Storage areas should be protected.
	Storage areas should be protected from excessively low temperatures to prevent freezing, and from excessively high temperatures to prevent degradation of the coating.
	General housekeeping must be rigorous to prevent bacterial or fungal growth.

When applying the coatings in humid and/or cold environments they should be force dried at a low oven temperature of approximately 120-150°F. If one does not have an oven, consider blowing air over the parts to promote the evaporation of water from the coating film. Failure to do so can lead to a poor quality film, initially resulting in handling damage, possibly the early onset of corrosion, and other premature failures.

Water reducible, or *water thinnable alkyds and modified alkyds* are similar to the solvent based alkyds with which most of us are familiar. Like the solvent based coatings, they are modified polyesters, but have high acid values and employ special chemical blocking agents, such as carboxylic acid functionalities. When the alkyds are neutralized with ammonia or volatile amines, it is possible to use water as the reducing liquid.

Although they may take longer to dry, the resulting coatings have similar gloss, flow and leveling properties compared with their solvent borne counterparts.

The *acrylic latexes* include other polymers such as vinyl acrylic and styrene acrylic. The resins are characterized as high molecular weight polymers dispersed as discreet particles in water. Those formed by polymerizing a single monomer are called *homopolymers,* while those polymerized from a blend of two or more different monomers are called *copolymers.*

Because the desired film characteristics which can be built into the resin by the choice of the monomers used, most of the latexes which are used for coating miscellaneous metal parts are copolymers.

Latex coatings, like lacquers, do not go through a chemical change as they dry. The characteristics of hardness,

flexibility, chemical resistance, abrasion resistance, physical and chemical attributes are derived from the basic latex polymer and specific modifications.

Acrylic latexes are known for their good exterior durability and excellent resistance to ultraviolet (UV) degradation. When used for outdoor exposure they retain their original gloss and color over longer periods. In this regard they are superior to unmodified alkyds, which tend to have poorer gloss and color retention.

Acrylic epoxy hybrids are less commonly specified. They comprise two- or three-package systems in which emulsified *epoxies* are used to crosslink aqueous acrylics. Properly formulated coatings are corrosion resistant and can produce finishes that have very good gloss, hardness, alkali and abrasion resistance. Unlike conventional solvent based epoxies, some mixed waterborne coatings have pot lives up to 36 hours at reasonable ambient temperatures.

Acrylic epoxy hybrids are used in applications where the hardness, flexibility and chemical resistance of an epoxy is desired. These coatings will be used for general metal finishing where high performance in terms of physical and chemical properties are not required, but improvements over the acrylic latex is preferred.

Epoxy water reducible coatings which air/force dried below 194°F (90°C) and with VOC levels at or below 2.8 lbs/gal (340 g/L) are available from a few vendors. Generally, they are supplied as two- or three-package systems. In the later case, neither components A nor B contain water. However, after they have been mixed in prescribed proportions water is added in fairly large quantities to adjust viscosity to sprayable levels, usually in the range of 20 seconds on a Zahn #2 cup.

The most commonly available water reducible epoxies are formulated as primers complying with military specifications MIL-P-53030 (lead- and chromate-free) and MIL-P-85582 (containing chromates). They can be topcoated with most other coating systems, in particular, polyurethanes, and are used when good corrosion resistance is required. As with all high performance coatings, properly prepared surfaces are mandatory. You might consider specifying the water reducible epoxies when you require better corrosion resistance than can generally be obtained from alkyd and alkyd modified primers.

Because epoxies tend to chalk when exposed to weather and sunlight (whether water or solvent borne) they are usually not used as topcoats. However, vendors do formulate these epoxies as topcoats where high performance is a requirement.

As primers, they are commonly specified for military hardware, steel and aluminum frames and weldments, cold rolled steel panels and cabinets, aerospace and electronic components.

Table III. Acrylic Epoxy Hybrid Air/Force Dry < 194°F (90°C)

Advantages	*Disadvantages*
Coatings crosslink to form insoluble, thermoset films.	Requires mixing of two or three components.
The acrylic portion provides ultraviolet (UV) resistance which appreciably improves chalk resistance, gloss and color retention on exterior exposure.	If coatings are dried in low temperature and/or high humidity environments poor films may form, leading to degraded physical and chemical properties.
The epoxy portion improves adhesion and alkali resistance.	Surfaces to be coated must be free of traces of oil and grease.
The very long pot life (36 hours at normal) ambient temperature), of the mixed and catalyzed coatings greatly adds to their utility.	Improper surface preparation or mixing can cause edge pull, poor substrate wetting and cratering.
The pre-cure, low molecular weight helps gloss development so that high gloss finishes are possible.	Material handling and application equipment must be of corrosion resistant materials due to the corrosive nature of the liquid coating.
Water is used for thinning and clean up, reducing costs of clean up.	Storage areas should be protected from excessively low temperatures to prevent freezing of the coating.
Increased safety due to low flammability may result in lower insurance costs and better working conditions.	Storage areas should be protected from excessively high temperatures to prevent degradation of the coating.
May be applied by most conventional spray equipment, but may not be compatible with airless and air assisted airless spray guns.	General housekeeping must be rigorous to prevent any bacterial or fungal growth that can interfere with product quality. Plant personnel must be trained in this preventive maintenance.
	The paint operator may need to go through some form of training to how establish the correct spraying viscosity.

Table IV. Water Reducible Epoxy Air/Force Dry < 194°F (90°C)

Advantages	*Disadvantages*
VOC levels at or below 2.8 lbs/gal (340 g/L).	Two- or three-component systems comprising base (A), catalyst (curing agent) (B) and water.
Primers are available with chromates, or lead and chromate-free.	Must be applied to properly prepared surfaces.
Primers comply with military specifications MIL-P-85582 and MIL-P-53030.	Depending on formulation, can be difficult to mix components A and B, due to their high viscosity. After adding water, the viscosity drops to manageable levels.
Dry to recoat quickly, even in highly humid environments provided that there is good ventilation.	Must be mixed using prescribed procedures.
Compatible with many types of topcoats, especially polyurethanes.	Relatively expensive as packaged, but competitive with solvent based epoxies.
Can be applied with most types of spray equipment, but may not be compatible with airless and air assisted airless spray guns.	Pot life can vary from about 6 hours to more than 8 hours, depending on air temperature and humidity.
Primer available in small range of colors.	Sometimes difficult to clean equipment and skin.
Topcoats can be made in a range of colors and gloss levels.	

Table V. Polyurethane Dispersions

Advantages	*Disadvantages*
Coatings made from polyurethane dispersions dry to tough films of dependable hardness and flexibility.	These coatings have the typical problems of waterborne finishes: drying time is dependent on temperature and relative humidity.
Coatings for metals, textiles, leather, wood, glass, paper and rigid plastics are made from these versatile products.	Like most lacquers, total nonvolatiles are quite low (35-40% by weight) so multiple coats are necessary for good film buildup.
Applications by most commonly used equipment with water thinning and clean-up.	Unlike solventborne lacquers, care must be taken to ensure good intercoat adhesion because the topcoat does not tend to dissolve any previous coats.
Very little, if any, solvent and only very small quantities of coalescing aids are used.	Surface cleanliness and freedom from any oil or grease both on the surface and in application equipment is essential for good film quality and adhesion.
Films dry to predetermined gloss and color and, because they do not chalk, both gloss and color retention are excellent.	
Like all lacquers, no chemical change occurs during drying and exposure so the dry films retain their original properties for long periods.	

Table VI. Alkyds, Modified Alkyds and Acrylic, Water Reducible Bake > 194°F (90°C)

Advantages	*Disadvantages*
Coatings are available at VOCs less than 3.0 lbs/gal (360 g/L), *less water*, and some even below 2.3 lbs/gal (275 g/L).	Require high temperature oven, 250-400°F (121-204°C) for more than 10 minutes.
Excellent film performance, often equivalent to polyurethanes.	High energy usage.
For metal substrates only, due to high temperature of bake, except perhaps for high temperature plastics.	Not for use on plastics, and other heat sensitive substrates, except perhaps some high temperature plastics.
No pot life limitations; one-component material.	Unreliable performance on porous castings due to outgassing, unless special precautions are taken to minimize the problem.
Water is primary solvent.	Touch up may require second bake or use of another air dry coating.
Can be spray applied with standard application equipment.	Not applicable where parts such as machined surfaces have tight dimensional tolerances and cannot tolerate warpage.
Touch up and repair with itself is possible, although this should first be confirmed by experimentation.	Surface cleanliness is more critical than for solvent systems.
Available in wide range colors, gloss levels, and can be used for texture finishing.	As with most resin systems which cure at elevated temperatures, color changes can occur if the coating is overbaked.
Meets industry standards for many top of the line applications, such as computers, business machines, lighting fixtures, appliances, automotive, coil, etc.	
Available as primers and topcoats, although can sometimes be applied directly to metal without the need for a primer.	
Low fire hazard and lower toxicity than solvent based systems.	
Lower costs for reducing solvents and cleanup.	

As with all other resin systems, particularly waterbornes, proper pretreatment of the substrate is essential.

Polyurethane dispersions are waterborne systems which can air/force dry at temperatures below 194°F (90°C). Essentially, they are polyurethane lacquers dispersed in water, which implies that as the water evaporates, the coating film is formed. No other curing mechanisms take place. In fact, they are completely reacted products with no free isocyanate groups, and after the water has evaporated the film is as hard as it ever will be.

Apparently, very low VOC contents are achievable; however, the technology is relatively new and is still in the process of being tested by various companies. While the polyurethane dispersions can be used on metal parts, much like the conventional two-component polyurethanes, the primary focus at the present time is in the wood finishing industry.

All the coating systems discussed so far can be dried and cured either at room temperature, or force dried in low temperature ovens, less than 194°F (90°C). As was pointed out earlier, the alkyds, modified alkyds, acrylic latexes and acrylic epoxy hybrids are excellent choices for applications in which superior physical and chemical properties may not be required. However, there are a wide range of waterborne resin technologies which do perform extremely well when exposed to chemical environments. Among them are the alkyd, alkyd modified, polyester and acrylic water reducible which cure at temperatures of 250°F (121°C) and above. The upper temperature limit is usually in the 350 to 400°F (162 to 204°C) range.

This group of coating formulations are water reducible or water thinnable and are similar to their solvent based counterparts in chemical structure. Like their solvent based counterparts, these resins are modified with aminoplast resins to allow for cross linking at elevated temperatures.

Typically these coatings are used where any of the following properties may be required; hardness, mar and abrasion resistance, excellent color and gloss retention, particularly when the coating is exposed to sunlight, chemicals, detergents and solvents.

End uses include metal office furniture, large appliances, supermarket shelving, computer main frames and metal hardware for the computer and business machines industry, metal laboratory equipment, bicycle frames, lighting fixtures, automotive and transportation applications where the components can withstand the relatively high baking temperatures.

As regards compliance with VOC

regulations, formulations are readily available which will satisfy 3.0 lbs/gal, (360 g/L), less water, and some are even below the 2.3 lbs/gal (275 g/L) levels.

CONCLUSIONS

This paper has discussed a comprehensive selection of waterborne coating technologies which can be used in a wide range of industries. Waterborne coatings can be applied to most all types of substrate—metal, plastic, wood, glass, and masonry surface.

These coatings are commercially available at low VOC levels and satisfy even the most stringent regulations.

Depending on the resin system and coating formulation, a full spectrum of physical and chemical performance properties can be expected. Therefore, companies which now need to get into compliance with the air quality regulations, can and should consider waterborne coatings as possible candidates.

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