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Guide to Cleaner Technologies

Organic Coating Replacements

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GUIDE TO CLEANER TECHNOLOGIES

ORGANIC COATING REPLACEMENTS

Office of Research and Development
United States Environmental Protection Agency
Cincinnati, OH 45268

NOTICE

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Users are encouraged to duplicate portions of this publication as needed to implement a waste minimization plan.

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SECTION ONE
INTRODUCTION

What is a Cleaner Technology?

A ***cleaner technology*** is a source reduction or recycle method applied to eliminate or significantly reduce the amount of any hazardous substance, pollutant, or contaminant released to the environment. The emphasis of cleaner technologies is on process changes that can prevent pollution. Pollution prevention occurs through ***source reduction,*** i.e., reductions in the volume of wastes generated, and ***source control*** (input material changes, technology changes, or improved operating practices).

Cleaner technologies include process changes that reduce the toxicity or environmental impact of wastes or emissions. Processes that reduce waste toxicity by transferring pollutants from one environmental media to another (e.g., from wastewater to sludge or from air emissions to scrubber wastes) are not inherently cleaner and are not considered to be source reduction.

Cleaner technologies also include recycle methods, but recycling should be considered only after source reduction alternatives have been evaluated and implemented where technically feasible. Where they are used, recycling techniques should occur in an environmentally safe manner.

Why Use Organic Coatings

Organic paints and coatings serve the primary functions of surface decoration and surface protection. Approximately 50 percent of the paints and coatings used in the United States are for protection and decoration of new and existing construction (architectural and industrial maintenance coatings), while 30 percent are used to protect and/or decorate industrial products (original equipment manufacturer or OEM product finishes). The remaining 20 percent is used for special purpose or miscellaneous applications such as traffic paint, automotive refinishing, high-performance coatings for industrial plants and equipment, and protection of marine structures and vessels (Bureau of the Census, 1992). Table 1 describes the major subcategories of the OEM product finishing and special purpose applications segments of the coatings industry.

Architectural coatings are applied on site to interior or exterior surfaces of residential, commercial, institutional, and industrial buildings. They are applied for protection and appearance, and cure at ambient conditions.

Table 1. The OEM and special purpose coatings markets.

Original equipment manufacturer (OEM) category:	
Metal containers	Beverage and food cans, other metal containers
Wood furniture and fixtures	Furniture, kitchen cabinets, and other millwork (doors, windows, trim, moldings)
Machinery and equipment	Farm and construction equipment, electrical machinery, refrigeration and heating equipment, general industrial machinery and equipment, computers and office equipment
Automotive	Topcoats, underbody paints, and primers applied to automobiles and light trucks; coatings for automotive parts
Coil coatings	Coatings applied to continuous coils of steel or aluminum, later fabricated into products by the household appliances, transportation, building, and containers industries
Wood and composition flat stock	Hardboard, plywood and particleboard fashioned into panels
Special-purpose coatings category:	
High-performance maintenance coatings	Coatings applied to protect metal and concrete structures as well as tanks, pipes, and processing equipment from the effects of corrosive environment
Marine coatings	Applied to steel and aluminum structures exposed to marine environments such as ships, offshore oil and gas structures, and other structures
Highway and traffic paint	Coatings used for marking lanes and placing directional signs (e.g., arrows) on the road surface
Automotive refinishing	Coatings used for repair work on cars, trucks, buses, and motorcycles

OEM product finishes are applied to factory-made articles as part of the manufacturing process. Coatings may be applied onsite by the product manufacturer or offsite by custom coaters. A wide range of coating types and application techniques may be used. These coatings may cure at ambient conditions or at elevated temperatures.

Industrial maintenance coatings are field-applied high-performance coatings formulated to resist harsh environments such as heavy abrasion, water immersion, exposure to chemicals or solvents, and/or high temperatures.

Paints and coatings are applied to surfaces to enhance corrosion resistance, provide one or more special properties (enhanced corrosion resistance, weatherability, durability), and improve appearance. Among the major industries that apply coatings are manufacturers of

- Automobiles
- Aircraft
- Appliances
- Wood products

Automobiles-The main function of automotive coatings are appearance, exterior durability, and corrosion protection. Typical automotive coatings use an undercoat or primer to give corrosion protection and improve durability. The topcoats are formulated to give the desired color and gloss. In some cases, a low-solids polyester basecoat is applied to give the color, followed by an acrylic clearcoat for a high gloss finish. Automotive coatings are normally applied on sheet steel, but body parts are increasingly being made from other materials such as plastic, composite, or stainless steel.

Aircraft--The main function of aircraft coatings are to resist the damage that can occur from corrosion, contact with fluids and fuels, erosion, temperature extremes, weathering, and impact. Coatings may also assist in providing protection for lightning strike. Appearance may be entirely cosmetic or, in the case of military aircraft, serve as camouflage. Aircraft finishes may be applied over aluminum, titanium, composite, or other substrates.

Appliances-Appliances are often referred to as “white goods” due to the traditional color of the coating applied. Nowadays a wide variety of colors can be applied to suit consumer tastes. Coatings are applied to protect the underlying metal from the effects of water, salt, detergent, and other common household agents at temperatures in the range of about 0°C to 100°C (32°F to 212°F). The substrate is typically sheet steel.

Wood products-Wood products such as furniture, siding, and doors are coated to increase durability and improve appearance. Exterior coatings must have greater weather resistance than coatings on items intended for interior use. Color or clear coatings may be chosen depending on the type and quality of the wood substrate and the intended end use.

In addition to the specific examples described above, coatings are used in a wide variety of other industries and applications. Other markets for unique coatings include: paper finishes, machinery, packaging materials (e.g., containers), sheet metal, coil, and truck, bus, and rail equipment.

New coatings are being formulated to meet customer needs, including environmental criteria. Coatings markets now influence coating chemistries and application techniques to a substantial degree. The wide range of applications and the increasing environmental requirements of the coatings markets indicates the cross-industry applicability of cleaner organic coating technologies.

Pollution Problem

Classical organic coating materials consist of dilute solutions of organic resins, organic or inorganic coloring agents, additives, and extenders dissolved in an organic solvent. The organic solvent gives the liquid coating the necessary viscosity, surface tension, and other properties to allow application of a smooth layer of coating.

The liquid coating is brushed, rolled, sprayed, flowed, or otherwise applied to the surface. As the organic solvent evaporates, the organic resins polymerize to form the desired file.

Environmental concerns and increasing costs of organic chemicals and metals (zinc, chromium, etc.) are leading to changes in the formulation of organic coatings. Coating formulators and users are seeking alternative materials to reduce or eliminate use of volatile solvents and heavy metals, and generation of paint residues and wastes.

Typical coating solvents used in coatings formulations include methyl ethyl ketone, methyl isobutyl ketone, toluene, and xylene. A more detailed list is shown in Table 2. Coloring agents in paints can include inorganic pigments containing hazardous metals such as cadmium, chromium, and lead. Mercuric chemicals have been used as a paint preservative but this use is declining.

At present, the major environmental concern of the coatings industry is the emission of volatile organic compounds (VOCs), which react in the presence of sunlight to create photochemical ozone or smog. VOC-containing solvents used in the formulation of conventional liquid coatings evaporate during application and curing. VOCs are also released during cleanup operations, which remove paint from painting equipment, paint

Table 2. Representative organic solvents used in paints and coatings.

Name	Boiling Range (^{O}C)
Low Hydrogen-Bonding Solvents	
Varnish Makers and Painters (VM&P) naptha	119-129
Mineral spirits	158-197
Toluene	110-111
Xylene	138-140
High flash naptha	181-201
1,l,1-Trichloroethane	73-75
Hydrogen-Bond Acceptor Solvents	
Methyl ethyl ketone	**80**
Methyl isobutyl ketone	116
Methyl n-amyl ketone	147-153
Isophorone	215-220
Ethyl acetate	75-78
Isopropyl acetate	85-90
n-Buty! acetate	118-128
I-Methoxy-2-propyl acetate	140-150
2-Butoxyethyl acetate	186-194
1-Nitropropane-nitroethane blend	112-133
Hydrogen-Bond Donor-Acceptor Solvents	
Methyl alcohol	64-65
Ethyl alcohol	74-82
Isopropyl alcohol	80-84
n-Butyl alcohol	116-119
sec-Butyl alcohol	98-101
1-Propoxypropan-2-01	149-153
2-Butoxyethanol	186-194
Monobutyl ether of diethylene glycol	230-235
Ethylene glycol	196-198
Propylene glycol	185-190

Source: Wicks, et. a!. (1992).

lines, and spray booth surfaces. New coatings formulations and application techniques described in this guide can reduce VOC emissions from paint facilities.

Paint wastes are another environmental priority for the coatings industry. These wastes include paint overspray, defective coatings removed from parts, and wastes generated during color changeovers. Reformulated coatings and newer coating application equipment can also reduce or eliminate some of these wastes.

Regulatory Environment

The paints and coatings industry is regulated under the Clean Water Act (CWA), Clean Air Act Amendments (CAAA), Resource Conservation and Recovery Act (RCRA), the Right to Know provisions of the Superfund Amendment and Reauthorization Act (SARA), the Pollution Prevention Act (PPA), and additional state and local authorities. Currently, the major regulatory initiative that affects the coatings industry is the development of Maximum Achievable Control Technology (MACT) standards under Title III of the CAAA. Title III is a comprehensive plan for reducing emissions of hazardous air pollutants (or HAPS). EPA has identified major source categories of HAPS and is now developing MACT standards for these source categories. Table 3 identifies source categories in the paints and coatings industry targeted for MACT standards.

Table 3. Categories of major and area sources of hazardous air pollutants - surface coating processes.

- Aerospace industries
- Auto and light duty truck
- Flat wood paneling
- Large appliances
- Magnetic tapes
- Manufacturers of paints, coatings, and adhesives
- Metal can
- Metal coil
- Metal furniture
- Misc. metal parts and products
- Paper and other webs
- Plastic parts and products
- Printing, coating, and dyeing of fabrics
- Printing/publishing
- Shipbuilding and ship repair
- Wood furniture

Source: U.S. EPA (1992).

In addition to these and other federal standards, many coatings facilities must comply with local and regional regulations also designed to restrict VOC emissions. Some of the most stringent requirements are being developed in southern California where ozone and smog are major concerns. There, the South Coast Air Quality Management District (SCAQMD) has mapped out a three-tiered approach to bring VOC emissions in the district into compliance. These regulations address both application equipment and the VOC content of coatings. Other states with significant VOC restrictions in place or under development include Georgia, Illinois, Indiana, Michigan, New Jersey, New York, North Carolina, Ohio, Pennsylvania, South Carolina, Washington, and Texas (Huberfield, 1991).

Solvent and paint waste disposal procedures and RCRA requirements increase waste management costs, establish cradle-to-grave responsibility for wastes, and require the waste generator to maintain a waste minimization program.

Section 313 of Title III of SARA establishes toxic chemical release reporting requirements. Facilities in Standard Industrial Classification (SIC) codes 20 to 39 that meet company size and chemical quantity thresholds must file reports on the discharge and recycling of chemicals. The current list of reportable chemicals numbers over 300 and is scheduled to be expanded in the near future. Many of these are used in the formulation of paints and coatings or in their application.

In addition to RCRA requirements for a waste minimization program for all hazardous wastes, the Pollution Prevention Act of 1990 establishes a hierarchy for addressing pollution problems. The Act emphasizes prevention of pollution at the source as the preferred alternative, with recycling and treatment and disposal identified as less desirable options. Many states have also embraced the pollution prevention approach and now require certain categories of industrial facilities to prepare and submit pollution prevention plans detailing their efforts to reduce waste and prevent pollution.

Solution

Coating technology relies on covering a substrate material with an organic film having the desired protective, mechanical, optical, aging, and adhesion properties. Conventional organic coating technology uses dilute solutions of alkyd, polyester, epoxy, polyurethane, acrylic, viny!, or other resins in a volatile organic solvent. In conventional coatings formulations, the organic solvent performs a key function of promoting desired flow characteristics, thereby facilitating the coating application. Once applied, the solvent evaporates, leaving the resins and pigments behind to polymerize and form the dry coating.

Cleaner technologies for the coatings industry are based on reformulations of conventional organic coatings to reduce their VOC content, or modifications to application or curing techniques that allow for reduced, or in some cases zero, VOC content. Numerous cleaner technologies also reduce the generation of paint waste by improving the efficiency of coating transfer to the substrate.

What's in this Guide?

This guide describes cleaner technologies that can be used to reduce emissions and wastes from paints and coatings application. The objectives are:

- To identity viable cleaner technologies that can reduce emissions **and** waste generation through the use of modified paint and coating formulations or application and curing techniques.
- To provide resources for obtaining more detailed engineering and economic information about these technologies. This information can be used by an individual facility to evaluate the potential for integrating cleaner technologies into existing operations or planned expansions.

The following are the main pollution prevention issues discussed in this guide. In evaluating potential alternative processes and technologies for possible further investigation, the reader is advised to explore these questions as thoroughly as possible:

- What alternate coating processes are available or emerging that could significantly reduce or eliminate the pollution and/or health hazards associated with currently used processes?
- What advantages would alternative processes offer over those currently used?
- What difficulties would arise and need to be overcome or controlled if the alternative processes were used, including:
    - Would different or new pollution or health problems arise as a result of adopting it?
    - Would the product quality be different from present?
    - Would the process require significantly different process controls?
    - Would the consumer accept the substitute?

- Would the process require significantly different procedures for handling reject parts?
- Would production personnel need to develop significantly different skills?
- Would there be a need for significant capital investment?
- Would production rates be affected?
- Would production costs be increased?

This guide has been designed to provide sufficient information to users to help in selecting one or more candidate cleaner technologies for further analysis and in-plant testing. The guide does not recommend any single technology over any other, since site-specific and application-specific factors often can affect the relative attractiveness of alternatives.

The guide presents summaries of applications and operating information that can be used to support preliminary selection of cleaner technologies for testing in specific production settings. It is hoped that sufficient detail is provided to allow identification of possible technologies for immediate consideration in programs to eliminate or reduce emissions and waste generation.

Follow-up Investigation Procedures

This guide covers several cleaner coating replacement systems that are applicable under different sets of product and operating conditions. If one or more of these are sufficiently attractive for your operations, the next step would be to contact vendors or users of the technology to obtain detailed engineering data that will facilitate an in-depth evaluation of its potential for your facility. Section Five of this guide provides an extensive list of trade and technical associations that may be contacted for further information concerning one or more of these technologies, including vendor recommendations.

Who Should Use this Guide?

This publication is intended for facilities in all segments of the paints and coatings industry, including applicators of architectural coatings, finish coatings for parts and assemblies, and maintenance coatings. Although the guide discusses reformulation of paints and coatings to reduce pollution and emissions, its use is intended for facilities involved in the application of coatings rather than those that formulate, manufacture, and distribute them. For further information concerning pollution prevention in paints and coatings formulation, see Randall (1994).

The guide is intended for plant processes and system design engineers and for personnel responsible for process improvement, process design, and environmental compliance. Process descriptions within this guide allow engineers to evaluate options so that alternative coating materials or equipment can be considered for existing facilities and factored into the selection of new coating applications.

Many coatings facilities are under pressure from federal, state, and local regulators to reduce emission levels of VOCs and other pollutants. Small- to medium-sized shops are often at a disadvantage when it comes to making decisions concerning environmental compliance. This guide should be especially useful to these companies evaluating opportunities for pollution prevention.

Organization of this Guide

This guide describes available cleaner technologies for paints and coatings applications. Section Two discusses technologies for pollution prevention that are well established and that have been implemented in a wide variety of settings. Section Three addresses newer or more specialized technologies. Section Four deals with strategies for understanding and implementing pollution prevention technologies. Section Five provides list of information sources for further guidance. In addition, each section contains its own list of references relative to individual cleaner technologies.

Keyword List

Table 4 presents keywords that enable the reader to scan the list of technologies and identify those that are generally available and those that are less widely used. Some but not all of the emerging technologies may still in development or pilot stages.

Table 4. Keyword list - cleaner technologies for organic coatings.

General Keywords	Available Technologies	Technologies Under Development
Cleaner technology	High solids, solvent-borne	Vapor injection cure coatings
Pollution prevention	Powder coatings	Supercritical carbon dioxide as solvent
Source reduction	Waterborne coatings	Radiation-induced thermally-cured coatings
Source control	Ultraviolet- or electron beam-cured coatings	
Recycling		

The distinction between "available" and "emerging" technologies made in this guide is based upon the relative state of development of each group. It is not intended to reflect judgements concerning the ultimate potential for any one technology over any other.

Summary of Benefits

The cleaner technologies described in this guide are categorized as either "available" or "emerging", depending on their level of development and extent of adoption within the industry. Available technologies include commercially available processes that have been adopted by numerous coatings applicators and are perhaps being used for more than one application. Emerging technologies are less developed and are limited in commercial application.

Table 5 summarizes the pollution prevention, operational, and economic benefits of these coating alternatives. You may wish to scan this summary table to identify the cleaner technology options that best fit the operations and needs of your facility. Detailed discussions of the benefits and operational aspects for each cleaner technology are provided in Sections Three and Four.

Table 5. Summary of benefits - cleaner technologies for organic coatings.

	Available Cleaner Technologies					Emerging Cleaner Technologies		
Benefits	High Solids, Solvent-borne Coatings	Powder Coatings	Water-borne Coatings	Electro-deposition Coatings	UV/EB Radiation-Cured Coatings	Vapor Injection Cure Coatings	Supercritical Carbon Dioxide as Solvent	Radiation-Induced Thermally-Cured Coatings
Pollution Prevention:								
Eliminates solvent in coating		✔	✔ [6]		✔ [8]			
Reduces solvent in coating	[1]	✔	✔	✔	✔		✔	
Reduces solvent in cleaning operations		✔	✔	✔	✔			
Operational:								
Easy color blending	✔		✔		✔ [9]	✔	✔	✔
Easy color change	✔	✔ [3]	✔		✔ [9]	✔	✔	✔
Can apply coat greater than 1.5 mils thick	✔	✔		[7]	✔ [10]	✔	✔	✔
Can apply coat less than 1.5 mils thick	✔ [2]	✔ [4]	✔	✔	✔	✔	✔	✔
Ability to automate	✔	✔	✔	✔	✔	✔	✔	✔
Economic:								
Relatively low or medium capital cost	✔	✔ [5]	✔		✔ [11]	✔		
Relatively low or medium operating cost	✔	✔	✔	✔		✔		
Relatively low or medium skill to operate	✔	✔	✔	✔	✔	✔	✔	

Notes to Table 5

1. High solids formulations do reduce solvent in the coating when compared with low solids formulations. In many cases, however, high solids coatings represent the baseline for regulatory limits, and low solids no longer comply. For this reason, high solids are considered the baseline for solvent content, and consequently do not have a reduced solvent content even though they quality as a cleaner technology compared to traditional low solids coatings.

2. The ability to form thin coatings is a function of the spray equipment, and of the formulation. Polyurethanes, for instance, will spray on as thin coats while polyesters can only be applied in thick coats.

3. Color changing equipment for powder coating is available for relatively quick and easy changes. The maximum color change frequency that is manageable from an operational standpoint is in the order of a few per day. More frequent changes than this will hinder operations excessively.

4. Generally, it is difficult to apply thin coats with powder. Dependant on the application, however, some formulations allow thin coats, particularly polyester powders.

5. For medium to small facilities, it is easy and relatively inexpensive to start a powder coating operation.

6. Recent waterborne technologies will completely eliminate solvent. Waterborne formulations currently available still contain some solvent, however, often up to 2.8 lbs/gal VOC less water.

7. The thickness of the coating is dependant on the voltage potential. Thicker coats can be achieved with higher voltages but practical limits exist.

8. Some UV/EB coatings eliminate solvent. All UV/EB coatings contain reactive diluents, however, so it cannot be assumed that VOC content is zero.

9. Ease of changing colors is not a problem, but availability of colors is limited. Clearcoat is the most common coating cured with UV/EB radiation.

10. Thick pigmented coats take a longer time to cure under ***W*** radiation. EB curing is quicker because the electron beam punches through pigmented coatings more easily than ***W.***

11. W lamps are relatively cheap. Thermal ovens are not required, so overall capital cost is relatively low. EB systems, on the other hand, are costly because of the expensive electron beam generator.

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SECTION TWO
AVAILABLE TECHNOLOGIES

Introduction

This chapter describes cleaner technologies available for the organic coating industry that can reduce emissions of VOCs. In reducing VOCs, these technologies may also reduce generation of hazardous wastes and decrease worker exposures to hazardous air emissions.

HIGH SOLIDS COATINGS, SOLVENT-BORNE

Pollution Prevention Benefits

High solids, solvent-borne coating systems were developed to reduce emissions of volatile organic compounds (VOCs) released during curing. High solids coatings have been reformulated to meet regulated levels of VOCs while retaining the essential character of the low solids coating formulation. High solids coatings typically contain 275 to 420 g VOC/l of liquid coating (2.3 to 3.5 lb/gallon) (Pilcher, 1988). High solids coatings currently available are generally similar to low solids coatings in their application, curing, and final film properties, though there are important differences. The major difference is the higher viscosity of the high solids formulation, which often leads to increased film thicknesses.

A standard definition of high solids does not really exist in the coatings industry. “High solids” coatings are generally considered to contain more than 80 percent solids, while the term “higher solids” refers to coatings containing less than 80 percent solids but more than the 30 to 40 percent contained in low solids coatings (Munn, 1991).

High solids paints have not made the inroads that other systems such as powder coatings have in replacing conventional coatings. Particular problems include high viscosity, viscosity changes due to temperature variation, and storage stability. Other issues are control of film thickness and the drying characteristics of the film.

How Does it Work?

Creating a high solids formulation is not as easy as simply reducing the solvent concentration. A reduction in solvent concentration without other changes lead to an unacceptably high level of viscosity. Because polymer binders (resins) used in coatings have traditionally been of moderate to high molecular weight, the molecular weight of the polymer must be lowered to retain acceptable viscosity. Lowering the molecular weight of the polymer is problematic, as unmodified low molecular weight polymers produce an unacceptable final dry film when normal curing times are applied. To overcome performance limitations caused by these polymers, additives often are used to increase cross-linking during curing. However, with chemical modification, polymers can retain good coating properties and lowered viscosity (Storey, 1987).

Types of High Solids Coating Systems

High solids solvent-borne coatings fit into three general categories:

- air/force-dry
- baking
- two-component

Resin systems generally belong to one category, although some resins cross over between categories.

Air/Force-Dry Coatings

Air/force dry coatings cure by exposure to moisture or oxygen. Alkyd resins are most common in air-dry coatings. Modified alkyds are also popular, while styrene, siliconized and acrylic resins are less common. Air-dry alkyds are termed oxidizing or auto-oxidizing because they cure in air without baking or the addition of a catalyst (Wicks, et. al., 1992).

These coatings cure at low temperatures, below 180°F. Low temperature ovens can be used to speed curing by evaporating the solvent more quickly. Air-dry high solids coatings usually have longer drying, tack-free, and hardness curing times than their low solids counterparts. These properties can alter production possibilities if the applicator needs to wait longer before handling parts. For instance, if the coating remains soft for a longer time than previously, the coating may become scratched or damaged during handling operations. This may necessitate rework which adds to the cost and increases the amount of pollution generated.

The recent development of new resins has resulted in a range of fast-drying high solids air-dry acrylics suitable for general metal finishing. These resins are inexpensive, offer excellent flow and drying properties, good hardness, durability, and color and gloss stability, and do not suffer from air entrapment or sagging. Early air-dry coatings contained highly volatile solvents, causing the surface of the coating to dry first and trapping solvent underneath. The result was pinholing or solvent-popping in the finished film (Ballway, 1992). These high-solids acrylics are suitable for various metal finishing applications, and have both indoor and outdoor uses.

Bake Coatings

Bake coatings predominantly use acrylic and polyester resins, although some alkyds and modified alkyds are also used. These resin systems cure at high temperatures to form a crosslinked film. Crosslinking agents such as melamine-formaldehyde (MF) or blocked isocyanates are commonly used. MF coatings are usually one pack systems, catalyzed by a strong acid such ***as p-*** toluenesulfonic acid (Storey, 1987). Latent or blocked catalysts are used for fast cure and good pot life with melamine-formaldehyde crosslinked coatings.

High solids resins based on alkyds or polyesters have low molecular weights, and contain hydroxyl groups that can be crosslinked with melamine-formaldehyde resins.

Blocked isocyanate urethane resins are often used as high solids binders for baking systems because of their outstanding performance properties and broad formulation latitude. Urethanes based on blocked isocyanates require an elevated temperature to cure. The polyisocyanates have surprisingly low viscosities, which is an asset in high solids coatings. Aliphatic polyisocyanate cross-linking agents are recommended for superior weathering properties, especially their resistance to yellowing (Storey, 1987).

Temperatures in the range of 350°F to 400°F are needed to cure baking enamels, requiring the use of high-temperature ovens.

Two-Component Coatings

The name “two-component” refers to the presence of two separate coating solutions which are mixed together just before use. “Two-component” is also known as “two-pack” and “2K” (from the German word, Komponent).

Two-component systems cure by a crosslinking reaction between the two components: reactive resins, or a resin and a catalyst. Epoxies and polyurethanes are the most common two-component coating systems. Polyisocyanates serve as the crosslinking agents for polyurethanes (Wicks, et. al., 1992).

Two-pack polyol cured urethane resins are often used as high solids binders because of the excellent properties of the finished film and the low energy needed for curing. Urethanes based on two-component systems cure at lower temperatures than baking polyurethanes.

Two-component polyol urethane coatings are suitable for metal finishing applications where outstanding film properties are required. These coatings are also suitable for the automotive and machine tool industries because of their excellent resistance to solvents, lubricants, cutting oils and other chemicals. Urethane clearcoats for automobile finishes, for example, provide hard wearing films with exceptional chemical and abrasion resistance.

Urethane coating systems do pose some health and safety concerns. For example, isocyanates are toxic and can affect the respiratory system. Damage from low-level exposure is usually reversible, however, sensitization can occur. Sensitization can be temporary or permanent. Following chronic exposure to urethane coating systems, permanent lung damage has been observed (Rees, 1992). Stability and pot life of two-component urethanes can also be problematic.

Epoxy resin systems are the oldest form of high solids coating. Two-component, thick film, solventless resin formulations for specialty applications have been available for many years.

In a two-component reactive liquid coating system, two low-viscosity liquids are mixed prior to entering the application system. One liquid contains reactive resins, while the other contains an activator or catalyst that promotes polymerization of the resins. Conventional, airless, or electrostatic spray equipment can be modified to accommodate new coating materials such as two-component epoxies, polyurethanes, and polyesters. The two components are fed into the spray gun through separate metering devices. Flow control valves and cleaning valves are built into the spray unit to prevent the components from coming into contact with each other before release. Two-component systems enable coatings to be applied without the use of a volatile organic solvent. Some solvents might be used to clean up any unreacted liquids.

High temperature ovens are not required for curing two-component coatings.

Reactive Diluents

A class of compounds known as "reactive diluents" can replace some organic solvents with low molecular weight resins designed to react, crosslink, and form an integral part of the coating. The most important asset of reactive diluents is that they are VOCs when tested individually per EPA Method 24, but are not VOCs when the mixed coating is allowed to crosslink before subjecting it to EPA Method 24.

Operating Features

As with conventional formulations, high solids coatings can be applied using numerous methods including:

- Brush or roller
- Pouring or flow-coating/curtain coating
- Dipping
- Spraying by low-pressure equipment
- Spraying by high-pressure/air-assisted equipment
- Spraying by airless equipment

- Spraying by electrostatic equipment
- Spraying by high volume, low pressure (HVLP) equipment
- Application by turbine bell or rotating disk

Spray Application Systems

Depending on the formulation, high solids coatings may be of similar or greater viscosity than low solids coatings. Traditionally, high viscosity makes coatings difficult to atomize and achieve a uniform film thickness. Today, emerging formulations are tending towards lower viscosity and therefore easier spraying. These new formulations may be based on new resin systems, or additives which modify viscosity and rheology for easier spraying.

Lower viscosity high solids coatings can be readily applied with all types of equipment such as air spray, airless spray, air-assisted airless, HVLP, or electrostatic spray. High-solids coatings that have high viscosity (or that have been exposed to cold temperatures thereby raising the viscosity) are more problematic to apply with spray apparatus. Spray equipment should be tested with the new coating to see if a suitable finish is obtained. If necessary, fluid tips can be exchanged or new spray guns purchased.

Spray application problems stemming from high viscosity are often solved by use of an in-line paint heater to reduce viscosity. The heater raises the fluid temperature thereby lowering the viscosity. An alternative is to use a temperature-controlled spray booth and set the temperature for reduced viscosity while still maintaining operator comfort.

High-volume, low pressure (HVLP) and electrostatic spraying equipment are approaches to high-efficiency application that reduce overspray loss and raise transfer efficiency. HVLP uses low atomizing air pressures of less than 10.0 psi along with high volumes of atomizing air to apply paint with less velocity than standard air spray guns, reducing losses from coating overspray. Electrostatic guns charge the coating and then deposit it on parts which are grounded.

Airless and air-assisted airless spray systems are used to apply high solids coatings. These systems use hydraulic pressure to atomize the coating into small droplets, resulting in a fine spray.

Other Application Equipment

High solids coating formulations with higher viscosities can be applied with electrostatic turbine bell or rotating disk atomization spray equipment. Disk and bell turbine applicator systems are primarily used in production line applications. With disk or bell applicators, the coating is fed into a rotating insulated disk or bell. Centrifugal force causes the coating to spread to the outer edge of the bell or disk. Turbine powered bells have rotational speeds of up to 50,000 RPM while disks can achieve speeds of up to 40,000 RPM. The disk or bell has approximately 100 kV of electrostatic charge to ensure uniformity of the coating by improving atomization and transfer efficiency of the paint droplets.

Surface Preparation

Surface preparation techniques need to be more thorough when using high solids coatings. Low solids coatings contain substantial quantities of organic solvents which allow a certain amount of self-cleansing (or greater wetting) of the substrate. Grease and other contaminants are wetted or dissolved by the solvent, resulting in a cleaner surface on which the coating adheres. High solids coatings do not have as great a self-cleansing ability, therefore surface preparation must remove more of the grease and contaminants when using these coatings. Cleaning with organic solvents would defeat the purpose of low-VOC, high solids coatings. Luckily, other measures exist, including aqueous cleaning systems, abrasive blasting and other surface preparation like phosphating treatments. See for example U.S. EPA (1993), Mounts (1993) and Wang and Merchant (1993) for alternatives to organic solvent cleaning.

Required Skill Level

Although the application equipment is similar, more operator skill and attention is needed when using high solids coatings, mainly because of problems of higher viscosity. Substantial air temperature changes will alter coating viscosity and change film thickness unless the applicator can make adjustments. Film thickness control is difficult, however, particularly on complex-shaped parts. On complex shapes, thickness variation of between approximately 1 and 7 mils is possible because of differing build up of coating due to changing spray angles. A high solids coating with low viscosity and good rheology is easier to apply in a uniform thickness.

Applications

Products Finishing

High solids VOC-compliant coatings have been used to replace low solids formulations in lining drum interiors at Russell-Stanley Corp., of New Jersey. Coatings for steel drums need to have good chemical resistance. Historically this resistance derived from high molecular weight resins, however these formulations required significant solvent use to lower viscosity. The VOC-compliant formulation still uses high molecular weight resins for chemical resistance, but sprayability is maintained by means of heating the coating to reduce viscosity. Heating equipment for lowering viscosity was found to be cheaper than alternatives such as exotic formulations or afterburners to incinerate VOCs (MP&C, 1990).

High-speed turbine bell atomizers are being used to apply high solid coatings to zinc-coated steel doors. In addition to lower VOC emissions, the new high solids coating formulations use lower curing temperatures which are required by the heat sensitive foam insulation cores now used in steel doors. High solid coatings meet the highest adhesion rating in ASTM D 3359, and pass a 250-hr salt spray test per ASTM B 117 (Nelson, 1988).

High solids polyurethane materials that meet MIL-C832858 are available for use on aircraft and ground support equipment. These high solids formulations, which are formulated for electrostatic application (MP&C, 1988), contain 340 g to 420 g VOC/(2.8 lb/gal to 3.5 lb/gal). The pot life is reported to be 6 hr.

High solids coatings are also used for aluminum extrusions, office furniture, appliances, business machines, containers and many other OEM applications.

Automotive Applications

High solids coatings are also used as automotive primers, topcoats, basecoats, and clearcoats. Two-component polyurethane coatings are increasingly being used for clear topcoats on automobiles. In comparison to conventional acrylic-melamine and alkyd-melamine systems, two-component systems offer many benefits, including low solvent emissions; high gloss and body; flexibility; and weather, chemical, and stone chip resistance. In addition, two-component polyurethane coatings cure at lower temperatures than baking systems, reducing energy costs.

Cost

Since high solids coatings use application equipment similar to low solids solvent-borne coatings, the capital cost for booths, electrostatic spray applicators, and curing ovens are approximately the same. In fact, many existing application systems can be used with minor or no modification for high solids coatings. For low temperature applications or high viscosity high solids formulations, paint heaters may be required. VOC control equipment may be required if the high solids coating emits greater quantities of VOC than regulations allow.

High solids coatings are slightly more expensive than conventional coatings per unit of reactive resin. Preparation, application, cleanup, and disposal costs are similar for high solids and low solids coatings. A detailed comparison of the costs of high solids, conventional, powder, and water-based coatings can be found in Hester and Nicholson (1989).

Benefits

Benefits of high solids coatings are:

- They contain a lower concentration of solvents than conventional coatings reducing environmental, odor, safety, and health problems.
- The manufacture and curing of high solids coatings requires less energy than conventional coatings, reducing energy costs.
- High solids coatings are easier to store than conventional coatings because of lower solvent concentrations, reducing storage and handling costs.
- High solids coatings produce films with greater thickness than conventional coatings, allowing increased line speeds and reduced number of coats.
- High solids coatings are compatible with application equipment and techniques used in conventional coating systems.

Limitations

The disadvantages of high solids coatings include:

- High solids coatings have a tendency toward excessive flow. Coatings with higher solids content require lower viscosity resins creating a more serious problem of excessive flow. When applied to a vertical surface, high solids coatings also have a tendency to sag. Many additives are available that control flow and prevent sagging in conventional formulations. The effectiveness of these additives with high solids coatings, however, has not been demonstrated. The use of flow control additives can also result in additional problems, particularly gloss reduction.
- High solids formulations produce films with increased thickness, which can blister during the baking process.
- Since high solids coatings use low molecular-weight resins, it is possible for these resins to become volatile at elevated curing temperatures, resulting in reduced binder content, poor film formation, and greater VOC emission.
- The overspray of high solids paints tends to create a sticky mass, whereas conventional coatings have a dry, powdery overspray. As a result, spray booths become clogged, creating severe collection and disposal problems.

- The viscosity of high solids formulations is extremely sensitive to changes in temperature. Temperature variations in the workplace can cause problems in spray application. Thermostatic heating of the coatings in the pot or in-line might be necessary for easier application.

- High solids coatings take a longer time to cure than conventional coatings increasing the opportunity for dirt pickup on the film. Work areas, therefore, must be kept clean; some form of air filtration is recommended.

- Although high solids coatings use less organic solvents, they do not completely eliminate solvents.

- Two-component high solids coatings have shorter pot lives than single-component coatings.

- Incinerators or carbon adsorber pollution control equipment might be needed when applying high solids coatings to meet VOC regulations.

Tradeoffs

High solids coatings use application systems that are similar to those used with conventional solvent-based coatings, easing the transition. Both equipment operators and plant management prefer simple transitions rather than radical changes in equipment and procedures.

Although high solids coatings offer reductions in VOC emissions, these reductions are not as great as those gained with powder coatings, many waterborne coatings or various other coating technologies.

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POWDER COATINGS

Pollution Prevention Benefits

Powder coatings are attractive from a pollution prevention standpoint because:

- No solvents are used in the coating formulation.
- Essentially all of the coating is applied to the substrate (high transfer efficiency).
- There is little or no hazardous waste to dispose of.

How Does it Work?

Powder coating technology uses dry resin powders for coating substrates with thermoplastic or thermoset films. The coating is formed after a layer of powder is applied with a powder coating spray gun or fluidized bed tank to the substrate and heated, thereby melting the powder. Automotive, appliance finishing, outdoor furniture manufacturing, architectural and building industries all use powder coatings. A major driving force in the growth of powder coatings is attributed to increasingly stringent environmental regulations (Major, 1992).

Powder coatings usually are applied in a single coat. The thickness of the coat is typically greater than that used with a solvent-based finish. Powder coatings use resins in dry powdered form without volatile organic solvents. Volatile solvents are not needed because clean, dry compressed air acts as the solvent or fluidization agent for the coating. No VOCs are released because solvents are eliminated from the entire process. Furthermore, the coating equipment can be cleaned with compressed air, eliminating the use of solvent in cleanup. Lower solvent levels reduce worker exposure and fire and explosion hazards. Because VOCs are eliminated, expensive VOC destruction equipment (incinerators or carbon adsorbers) is not required.

Hester and Nicholson (1989) present the following example to show the potential VOC reductions achievable with powder coatings. A large conventional coating facility covers 12 million ft^2/yr of substrates with 1.2 mil-thick coats. The plant uses a VOC treatment system with a 70 percent capture efficiency. Emissions of VOC are approximately 38 tons/yr. By comparison, a powder coating facility using electrostatic application of polyester-urethane resins will emit only 0.6 tons/yr of VOCs, and avoids the need for emission control equipment.

Operating Features

Many different resins are available for powder coating. The two most general categories are thermoplastic and thermoset resins. Table 6 compares the properties of various thermoplastic and thermoset resins.

Thermoplastic resins

Thermoplastic resins form a coating but do not undergo a change in molecular structure. These resins can be re-melted after they have been applied. Thermoplastic resins are used mainly in functional coatings such as thick, protective coatings on dishwasher trays (Lehr, 1991).

Examples of thermoplastic resins used in powder coating are:

- Polyethylene
- Polypropylene
- Nylon
- Polyvinylchloride
- Thermoplastic polyester

These thermoplastic resins are designed for functional and protective uses, not as a replacement of thin film coatings from solvent-borne paints.

Thermoset resins

Thermoset resins crosslink to form a permanent film that withstands heat and cannot be remelted. These resins are ground into very fine powders that can be applied with a spray gun for thin film coatings. They are used for decorative, protective, coatings in architecture, on appliances, furniture, and elsewhere. Because thermoset systems can produce a surface coating that is comparable to liquid coatings, most of the technological advancements in recent years have been focused on these resins (Lehr, 1991).

There are five basic families of thermoset resins:

- Epoxies
- Hybrids
- Urethane polyesters
- Acrylics
- Triglycidyl isocyanurate (TGIC) polyesters

Table 6. Summary of powder coating resin properties.

	Resin Type				
Coating Property	Epoxies	Epoxy-Urethane Hybrids	Urethane Polyesters	TGIC Polyesters	Acrylics
Hardness	excellent	excellent	very good	excellent	very good
Flexibility	excellent	excellent	very good	excellent	fair
Resistance to overbaking	fair	very good	very good	excellent	good
Exterior durability	poor	poor	very good	excellent	very good
Corrosion protection	excellent	excellent	very good	excellent	fair
Chemical resistance	excellent	excellent	very good	very good	very good
Thin coat	no	no	yes	no	no
Colors available	all	all	all	all	all
Clears available	yes	no	yes	yes	yes
Textures available	yes	yes	Yes	yes	no

Source: Lehr (1991)

Epoxies-Epoxies have always been the staple of the powder coating industry. These materials cure at temperatures below 300^{0}F, many around 260°F. Mechanical surface properties are excellent; their pencil hardness can reach 7H, Impact resistance is approximately 160 inch-pounds. These resins also can be bent around a l/4 inch mandrel with no loss of adhesion. Corrosion resistance and chemical resistance is excellent with epoxy materials. Epoxies, however, have poor W resistance and consequently are best suited to indoor applications (Lehr, 1991).

Hybrids-Hybrid materials are combinations of epoxy and polyester resins designed for a good mix of characteristics, although their *W* resistance is still poor. The presence of polyester resins helps to slow down or reduce yellowing of the film that can be caused by overbaking.

Urethanes-Urethane polyesters are suitable for outdoor use because of superior exterior durability. Urethane polyesters have very good surface properties (hardness, flexibility, corrosion protection, etc.) although not quite as good as epoxies. Urethanes can be applied in thin coats; coats of 1 mil to 2 mils (25 microns to 50 microns) usually are recommended. Most other powder coat resins need to be applied in heavier coats, forming thicker films.

Acrylics-Acrylics have very good to fair surface properties, and are becoming more common in the U.S. Acrylic's good weatherability makes them suitable for exterior use.

TGIC-TGIC polyesters incorporate the cross-linking agent triglycidyl isocyanurate. TGIC resins produce films with excellent surface properties such as hardness, flexibility, exterior durability, and corrosion and overbaking protection. Coating thickness of 3 mils to 5 mils (75 microns to 125 microns) is recommended.

Exposure to trimellitic anhydride (TMA), a monomer used in polyester resins, has been reported to cause allergic reactions. Hybrid resins can help to reduce these reactions. TGIC resins, for example, have been used alongside TMA-based powders in ratio of 70:30 to reduce the potential for allergic reactions (Reich, 1993). TGIC-based resins, however, have been under attack. In Europe, reduced occupational exposure limits (OEL) were recommended for TGIC powders as a result of ***in vivo*** mutagenicity tests. In response, several chemical companies have launched alternative hardeners, including caprolactam-blocked isophorone diisocyanate (IPDI) adducts (Loutz, et. al., 1993).

As an alternative to blocked isocyanate cross-linking agents, melamine resins mounted on polymer support materials can be used for curing solid polyester resins. Advantages of these resins include lower curing temperatures, lower hardener-content, and lower volatile emissions.

The physical and chemical properties of the powder have to be carefully controlled. The effectiveness of powder coating depends on obtaining a smooth, nonporous film. Formation of a good coating free of voids, pinholes, and orange peel distortions depends on controlling the particle size distribution, glass transition temperature, melting point, melt viscosity, **and** electrostatic properties. Well-controlled size distribution is important in achieving good powder-packing on the surface.

Application Methods

Application systems for powder coatings include:

- Electrostatic spraying
- Tribocharge spraying
- Fluidized bed

These application techniques offer much higher transfer efficiency (TE) than wet-spray liquid coating methods for two reasons. An electrostatic charge causes an attractive force between the powder coating material and the substrate, resulting in higher TE than non-electrostatic solvent-borne or waterborne spraying. Second, wasted powder can be readily reused. Powder coating systems are designed to reclaim powder that has not formed part of the coating.

Electrostatic spraying-The most commonly used **powder** coating method is electrostatic spraying. Dry powder is applied to an unheated substrate and held in place by electrostatic force. The substrate or primer coat must be electrically conductive. A transformer supplies high voltage (typically 100 kV) low-amperage current to an electrode in the spray gun nozzle. The current ionizes the surrounding air, transferring a negative charge to the powder particles as they pass through the corona of ionized air. The substrate to be coated is grounded, allowing powder particles to follow electric field lines and air currents from the gun to the substrate (see Figure l)(Lehr, 1991; Loutz, et. al., 1993).

Compared to conventional air spraying of wet coatings, electrostatic spraying achieves greater coverage of the substrate because the powder tends to "wrap" around comers and coat surfaces that are not "line-of-sight" with the spray gun. This results in less overspray and consequently a higher transfer efficiency.

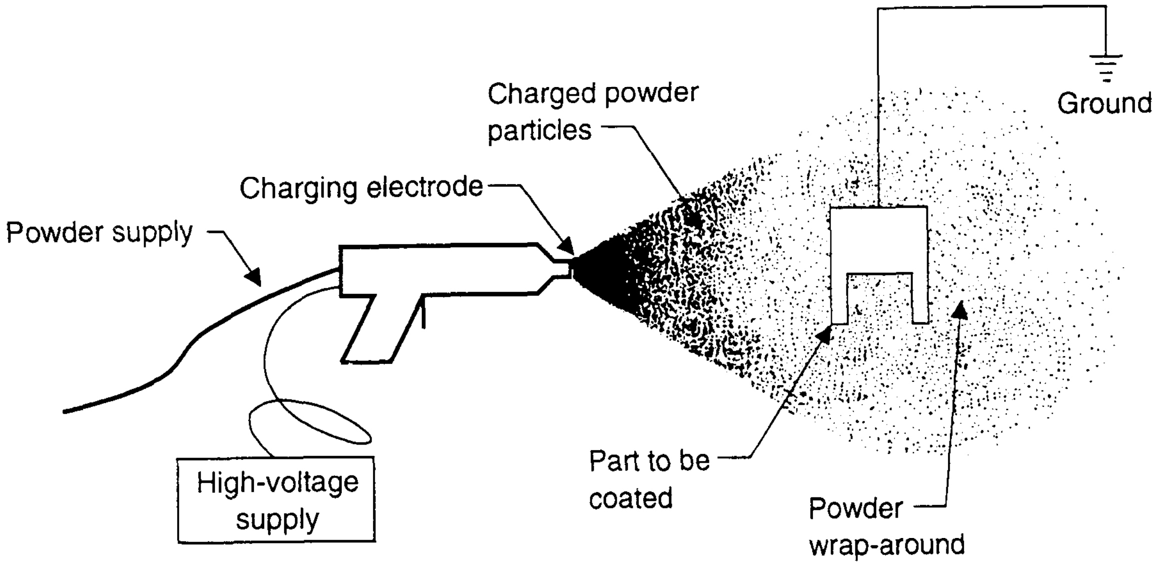
The following shortcomings of electrostatic powder coating led to the development of tribocharging:

(1) The thickness of the coating can be reduced on areas where the electric field is interrupted. This phenomenon is caused by the Faraday cage effect, which occurs when a hollow or other complex geometrical shape resembling a cage is found in the substrate. This shape distorts the electric field lines, causing uneven powder distribution.

(2) Air ions can become trapped in the coating and build up a strong electrical field, resulting in surface imperfections in the coating such as reduced thickness, orange peel-like distortions, and cratering (Loutz, et. al., 1993).

Figure 1

Electrostatic Spray Gun for Powder Coating



Source: Eastern Research Group, Inc.

Tribocharging-The basic principle of tribocharging relies on friction between the powder and the spray gun. The action of the powder flowing through the barrel of the gun generates a frictional charge on the powder. The charged powder is carried by air stream to the substrate where it deposits and sticks due to electrostatic attraction. Because there is no high-voltage system generating a field between the spray gun and the substrate, the electric field is substantially smaller and the powder tends to follow air currents rather than field lines. The smaller electric field results in a much reduced Faraday cage effect. Consequently, tribo guns produce smoother finishes, allow deposition of thicker films, and provide better coverage of intricately-shaped objects.

The frictional charge is generated because the powder and the gun have different dielectric constants. The tribocharging annular chamber is constructed of polytetrafluoroethylene (PTFE). Because PTFE has a low dielectric constant, a positive charge will be imparted to most powders. Some powders have low dielectric constants (e.g., mixtures of polyester and TGIC) and do not pick up electrical charges readily. Therefore, attempts have been made to modify the powder composition, Small quantities of additives such as amines or quaternary ammonium phosphate salts increase the ability of the powder to accept positive charges. Additives, however, can modify the reactivity of the powder and also create a non-uniform composition. Uneven composition can lead to powder segregation and create problems with recycling. Steps are underway to produce a polyesteramide that has increased ability to accept frictional charge, reducing the need for additives (Loutz, et. al., 1993).

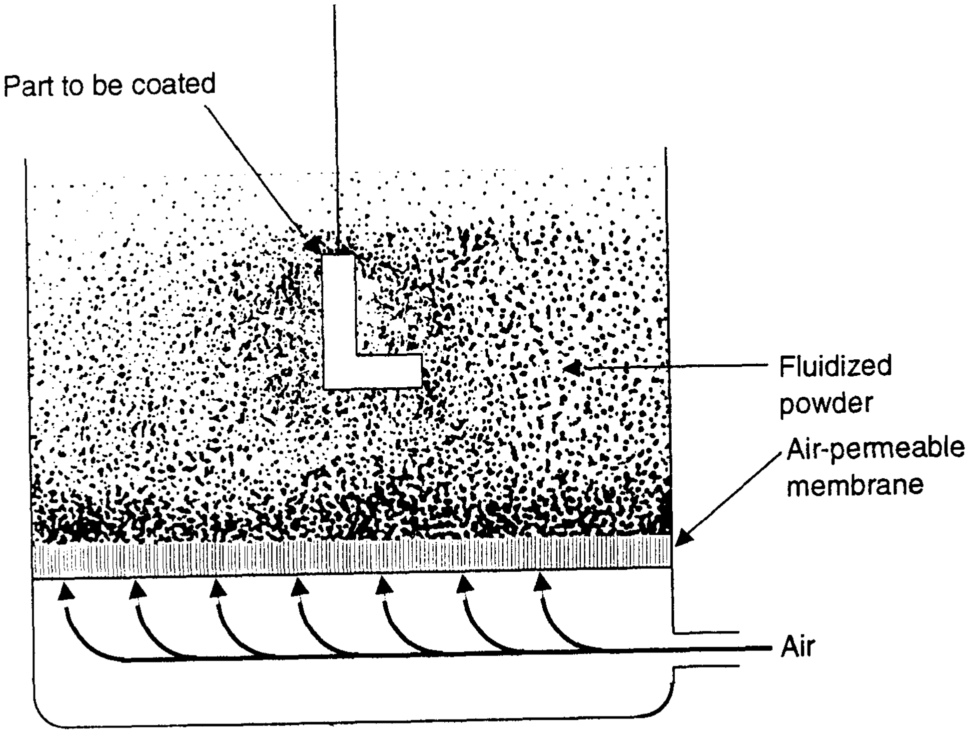
Tribocharging is less complex than traditional electrostatic powder coating systems because it does not use high-voltage transformers for applying the charge on the powder. Tribocharging guns do wear out faster than regular guns because of the abrasion of the powder on the PTFE surfaces. Because of the absence of electric field lines and a reduced dependence on leakage to ground of free ions, tribo guns are more suitable for painting nonconductive surfaces.

Fluidized beds-Fluidized beds provide another way of coating powder, similar in action to a dip tank (see Figure 2). Powder rests in a tank or hopper, which is fitted with a porous bottom plate. Low pressure dry air is circulated through the bed, causing the powder to attain a lofted, fluid-like state. The workpiece is preheated, usually to greater than 500°F then dipped into the tank. Powder melts on contact with the part forming the coating. This method allows fairly complete, uniform coverage of complex-shaped parts.

Fluidized bed systems are primarily used to apply coatings of thermoplastic powder to thicknesses in the range of 10 to 30 mils. The substrate is heated

Figure 2

Fluidized Bed for Powder Coating



Source: Eastern Research Group, Inc.

to a higher temperature than the melting point of the resin so, as particles strike the hot surface, they melt and coalesce to form a thick, continuous film on the substrate. During fluidized bed coating, powder is added to replace material that has formed a coating on the substrate. Because very little powder is lost or degraded during coating, powder utilization is near 100 percent. The fluidized bed method is the original method used for applying powder coatings, and is still the method of choice for heavy functional coatings (Lehr, **1991).**

A modification of this system is the electrostatic fluidized bed (see Figure 3). Here the powder receives a charge from air which flows through a high voltage charging system, while the object, which is grounded, is lowered or suspended over the tank. Variations on this principle allow wire mesh or other endless-type products to be coated. Electrostatic fluidized beds are limited to an effective depth of about 2 to 3 inches so that they are best suited to coating two-dimensional parts (Muhlenkamp, 1988).

Curing

Powder coatings must be "heat-cured" or melted on to the substrate. For thermoplastic resins, the substrate can be heated prior to coating so that the resin melts directly on application. Thermoset resins are normally cured in either heat convective or infra red ovens, or a combination of the two. The substrate must be able to withstand temperatures of 260°F or higher. Delicate substrates like certain thermoplastics or wood cannot be cured in ovens. The substrate must also be of a size and shape to allow immersion coating or heating in a curing oven. This prevents general indoor or outdoor application where heating options are not available.

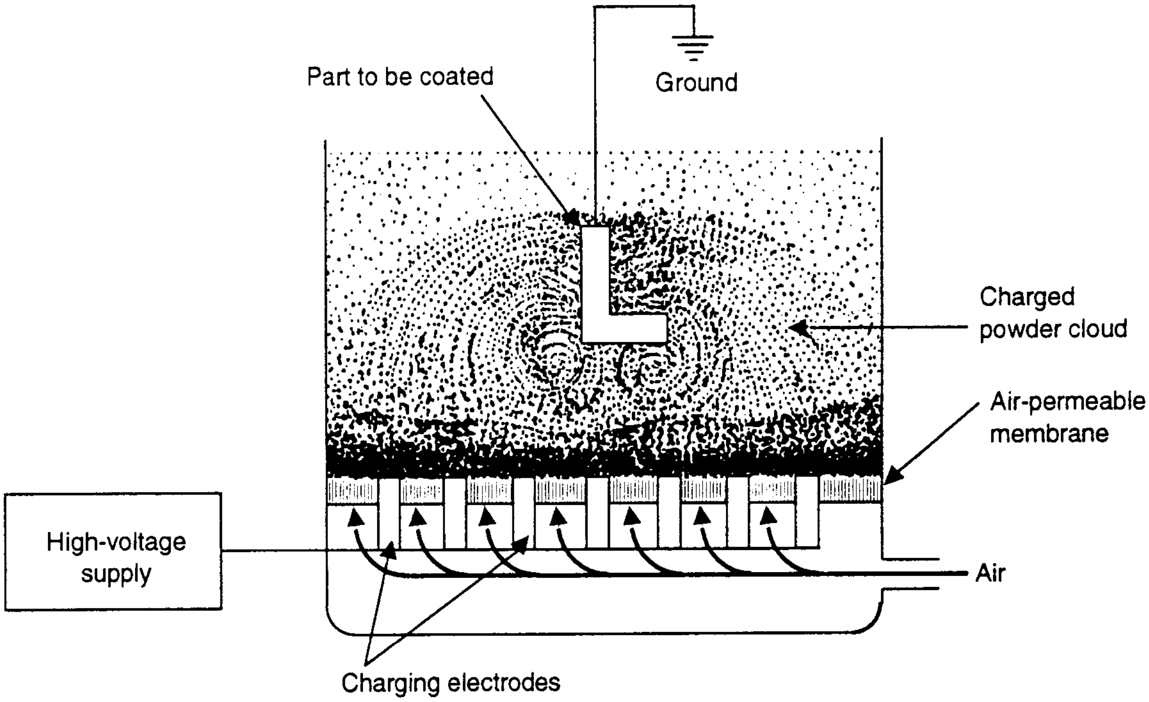
Certain thermoplastic powder coatings can be applied by a flame-spraying method. This technology, developed by Plastic Flamecoat Systems Inc. in Texas, uses a propane and compressed air flame in the spray gun to melt the powder as it is propelled towards the substrate. The molten powder hits the substrate and flows into a smooth pinhole-free coating (Major, 1992).

Thermoplastic powder coatings are used in military applications such air force weapon systems and aircraft. The ability to field repair these coatings using spray guns is valued in these applications (Ellicks, 1994).

Gas-fired ovens have considerable economic advantages over other energy sources, however, they can produce nitrous oxides which come in contact with the coating as it cures. Some grades of powder are more susceptible to yellowing under these conditions than others. Grilesta has developed several powders (grades P 7307.3 and P 7309.3) that can be used in gas-fired ovens without yellowing (Reich, 1993).

Figure 3

Electrostatic Fluidized Bed for Powder Coating



Source: Eastern Research Group, Inc.

Other Issues

Pretreatment of the part to be coated needs to be quite thorough. Because powder contains no organic solvents no cleansing action is available as the coating is applied to the part, therefore the substrate must be very clean, free of grease and other contaminants. Before powder is applied, the surface must be totally clean, dry and enhanced. This last term describes the condition of the surface which is attained after an acid wash or rinse. Typical pretreatment methods include sophisticated solvent cleaning systems, abrasive blasting or cleaning, and aqueous chemical cleaning. They are sold as complete systems and add cost to the overall powder operation (see Lehr (199 1) for further details).

If only partial coating of a part is required, the part needs to be masked to prevent powder from adhering to the entire surface. Large numbers of manufacturers need to mask parts and this can be a major problem, depending on the part and the degree of masking required.

Because powder coatings rely on large, fluidized bed reservoirs, it is more difficult to make color changes than with liquid coatings. Swapping frequently between a large variety of colors is time-consuming and problems with cross-contamination of color can occur. Powder is more suited to operations where color change is infrequent.

Powder Coating Equipment

With powder spraying equipment, powder is supplied to the spray gun by the powder delivery system. This system consists of a powder storage container or feed hopper with a pumping device that transports a stream of powder to the gun through hoses or feed tubes. A supply of compressed air often is used as a “pump” because the air separates the powder into individual particles for easier transport.

All spray guns can be classified as either manual (hand-held) or automatic (mounted on a mechanical control arm), however, the basic principles of operation are the same. Spray guns are available in a variety of styles, sizes, and shapes. The type of gun used can be selected to achieve whatever performance characteristics are needed for the products being coated.

Improvements have been made to spray guns to improve the coating transfer efficiency. Many of these changes involve variations in spray patterns. Nozzles that resist clogging have been introduced. Spray guns with variable spray patterns are also available for using one gun on multiple parts of different configurations.

The powder delivery system can supply powder to one or several guns, often located many feet from the powder supply. Delivery systems are available in many different sizes depending on the application, the number of guns to be supplied, and the volume of powder to be sprayed during a given time period. Recent improvements in powder delivery systems, coupled with improvements in powder chemistries that can reduce clumping, have made it possible to deliver a very consistent flow of particles to the spray gun. Agitating or fluidizing the powder in the feed hopper also helps to prevent clogging or clumping before the powder enters the transport lines.

Innovations in powder delivery systems allow the powder supply reservoir to be switched easily to another color powder when necessary. If the overspray collection system is also not changed, however, the collected powder will include all of the colors applied between filter replacements or booth cleaning. For collected oversprayed powder to have the greatest value, it should be free of cross-contamination between colors.

Numerous systems now are available for segregating colors, and that allow several colors to be applied in the same booth. Most of these systems use a moveable dry filter panel or cartridge filter that is dedicated for one color and that can be removed easily when another color is needed. Color changes are accomplished by:

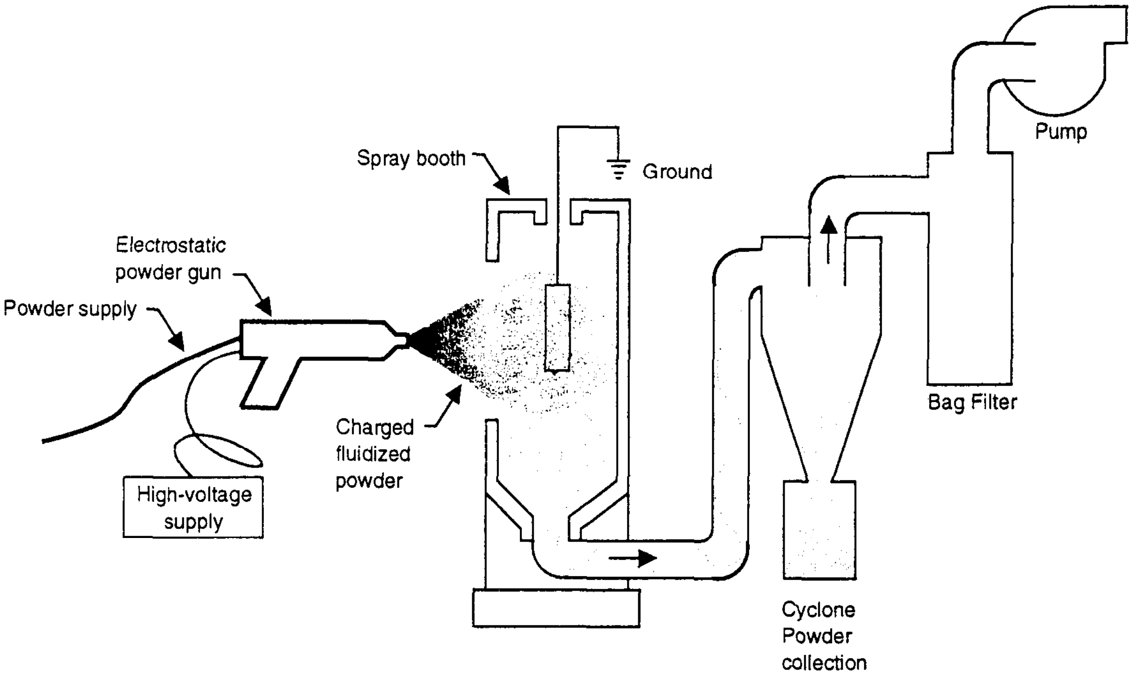
(1) disconnecting the powder delivery system and purging the lines;
(2) cleaning the booth with compressed air or a rubber squeegee;
(3) exchanging the filter used with the filter for the next color; and
(4) connecting the powder delivery system for the new color.

Equipment manufacturers have made significant improvements in design of spray booths, enabling color changes to be made with a minimal downtime and recovery of a high percentage of the overspray.

Electrostatic and tribocharged spraying both result in overspray of powder. However, unlike the overspray from most solvent coatings, powder overspray can be collected and reused. Figure 4 shows a schematic of a recycling system for powder coating. Recycling systems coupled with the inherently high transfer efficiency of powder coating results in reduced waste paint disposal, lowering both costs and environmental impacts. As with spray guns, a large number of spray booth and powder recovery designs are available to choose from, depending on the exact requirements of a given finishing system (Hester and Nicholson, 1989).

Figure 4

Powder Coating Recycling System



Source: Eastern Research Group, Inc.

Required Skill Level

Powder coating equipment and techniques are easier than those used for conventional dip coating or spray painting. The operator needs less skill than a comparable liquid spray painter. However, the operator does need experience with powder to determine if the deposited coating will result in a good film before the coating enters the oven.

Developments in Powder Coating

Powder coatings traditionally have had poor weathering properties, especially the common epoxies. Certain acrylic powders give better ageing and W weathering resistance. One of the better systems for high ***W*** resistance uses carboxylated polyesters cured with TGIC. In an accelerated weathering experiment, this system showed ***W*** resistance similar to an acrylic resin cured with TGIC hardener. Values for gloss retention are as high as 60 to 70 percent after 4 years exposure in Florida (Loutz et al., 1993)

Curing by IR radiation induces very rapid development of the crosslinked film, enhancing line speed, however viscosity of the film increases quickly, hindering transport of water during the curing process. Water evolved as a byproduct from the crosslinking reaction can be trapped in the film leading to problems of severe pinholing and gloss reduction (Loutz et al., 1993).

Based on epoxy/polyester hybrids, thin-layer coatings are now available in the range 1-l.2 mils (25 to 30 microns) for colors with good hiding power. Currently these are only suitable for indoor applications because the epoxies degrade on exposure to outdoor weathering (Major, 1992).

Thin coats may be desirable where protection from corrosion and other environmental factors is not so important. The reduced thickness directly reduces the amount of powder needed and consequently the cost of the coating. For thin coat application, the powder particle size is approximately 25 microns, and must have a narrow size distribution (Loutz et al., 1993).

When thin coats are applied, impurities in the powder can give rise to visible surface defects such as cratering. For this reason, the resin is carefully filtered to remove traces of gel, unreacted monomers and other non-soluble materials. Thin coatings show surface imperfections more readily than thick coatings. Small amounts of thermoplastic resin can be added to the formulation and this will act as a permanent plasticizer and reduce the melt viscosity, giving better flow to the finished coating (Loutz et al., 1993).

Growing concerns over solvent and solid waste emissions from solvent-borne coil coating operations have led to use of powder for coil coating. Powder formulation technology has advanced and current powders are now highly formable and stain resistant, allowing their use in coating coil stock manufactured for domestic appliances such as refrigerators, washing machines and microwave ovens (Loutz et al. 1993).

Blank coating by powder offers similar benefits to coil coating. Flat metal blanks are cut and cleaned before powder coating, then formed into the part. One advantage is high speed of operation; blanks are cut, cleaned, coated and cured in as little as two minutes. Other benefits include uniform film thickness, high transfer efficiency and a compact finishing operation (Major, 1992).

Low-gloss coatings are now available with good mechanical surface properties and appearance. Gloss values range from 1 percent or less with epoxies to approximately 5 percent for weather-resistant polyesters (Major, 1992).

Textured powder finishes range from fine textures with low gloss to rough textures suitable for hiding an uneven surface on the substrate. Textured powder coatings have shown large improvements in mechanical and processing abilities compared to those of several years ago (Major, 1992).

Metallic powder coatings incorporate metal flakes which are blended with the powder before being sprayed onto the substrate. Aluminum extrusions are commonly coated and efforts are concentrated on matching anodized parts. A clear topcoat over the metallic base improves exterior durability of the coating (Major, 1992).

In-mold powder coatings allow manufactures of certain molded plastic products to coat with powder during the molding operation. Powder is sprayed into the mold before-the molding compound is added; the powder then melts and cures, chemically bonding to the molding compound and producing a finish with excellent surface properties such as chip and impact resistance. Suitable substrates are sheet molding compounds and bulk molding compounds, used to produce automotive body panels and other items (Major, 1992).

Polyester and acrylic powder coats have been developed for outstanding weather resistance. Powder coatings can meet all the requirements of AAMA 603 and 605 specifications, except the Florida five-year exposure test which is still underway (Major, 1992).

Powder coatings with very high reactivity have been developed to cure at 250°F; these allow higher line speeds (increased productivity) and greater use of heat-sensitive substrates. Shell Development Company in Houston is working on low-temperature cure epoxies that have adequate physical and chemical properties to allow exterior use. (Major, 1992) Adding a selective catalyst, such as Crylcoat 164, to a conventional polyester allows curing at reduced temperatures of approximately 260°F to 280°F. Two major drawbacks are a risk of premature reaction during the extrusion process and poor surface appearance because of partial crosslinking before complete fusion of the powder (Loutz, et al. 1993).

American Cyanamid Co. produces a solid amino cross-linking resin for powder coatings with the tradename Powderlink 1174 (tetramethoxymethyl glycoluril). This resin can be used with either hydroxyl function polyesters or acrylics to produce highly durable, light-stable coatings with good mechanical properties. The cross-linking resin has low toxicity, low environmental impact, and both performance and economic advantages. An internally catalyzed polyester, designed for use with 1174, is commercially available. The polyester has wide cure responses along with good film appearance and other properties (MP&C, 1992).

Applications

Applications of powder coating are growing rapidly because of numerous benefits, including lower cost, higher quality, and increased pollution prevention opportunities.

Materials suitable for powder coatings include (Robison, 1989; Bowden, 1989):

- Steel
- Aluminum
- Galvanized steel
- Magnesium
- Aluminum, magnesium, zinc and brass castings
- Plated products

Product Finishing

Powder coatings are used commercially for a wide range of small- to medium-sized metal parts, including lighting fixtures, equipment cabinets, outdoor furniture, heat exchangers, microwave antennas, shelving, and hand carts and wagons. Radiation Systems, Inc., based in Virginia, coats microwave antennas with polyester powder, forming a coating that is resistant to physical damage, solar radiation and environmental effects (P&SF, 1992).

Powder coatings are firmly established in industries that manufacture metal furniture, lawn and garden equipment, store shelving, exercise equipment and aluminum extrusions. Job-shop electroplaters have adopted powder coatings to meet customer specifications and environmental regulations (CMR, 1993).

Clear coatings, especially topcoats, are increasing in importance. The automotive industry use clearcoats on wheels, trim and other fittings. Bicycle manufacturers also use powder clearcoat when performance and quality count more than small cost increases (Reich, 1993).

Automotive components coated by powder include vacuum booster housings, door handles, steering columns, oil filters, aluminum wheels, shock absorbers, and antennae, among others. Toyota, General Motors and Chrysler use powder coatings for door frames, and, in some instances, for lower body anti-chip coatings. Powder coating is used as an effective primer surfacer, and for blackout finish. Current activity is focused on applications for light trucks and sport-utility vans. General Motors, for example, applies primer surfacer and blackout finishing to Chevrolet S-10s and Blazers (Cole, 1993).

Industrial and Architectural Finishing

Powder coatings are used to protect many parts of buildings, both exterior and interior, residential and commercial. Polyester powders are applied in controlled factory settings to aluminum and galvanized steel profiles and sheet products for use in windows, doors, curtain walls and exterior cladding. Fusion-bonded epoxy powder coatings are used for protection of steel reinforcing bar and mesh in concrete structures. Polyurethane or polyester powders finish many ancillary components in the building industry, such as downpipes, lampposts, fencing, railing, street furniture and other metal parts. Epoxy and epoxy/polyester hybrid powders are not suitable for exterior use and therefore coat interior components including air-conditioners, light fittings, partitioning and radiators (P&II, 1991; P&SF, 1993).

Polyester powder coats can be applied to galvanized steel, producing strong, corrosion-resistant and visually pleasing architectural components, however, problems with “pinholing” and poor adhesion have undermined powder’s reputation in this area. Pinholing is unique to galvanized steel and although unsightly, it does not impair corrosion resistance. Pretreatment of the metal surface is necessary to reduce pinholing. A vigorous cleaning regime involving a soak clean, an etching cleaner, a chromate solution and various cold and de-mineralized water rinses is recommended (Metallurgia, 1991).

Industrial powder coatings can provide a corrosion-resistant finish without pretreatment such as priming or even sandblasting [according to Manchester Industrial Coatings Ltd]. Powder coatings applied to substrates that had not been pretreated were, upon testing, found to be resistant to conditions encountered in the North Sea and eastern Asia (AMM, 1991). Powder coating without any pretreatment should be considered quite risky. Proper testing needs to be applied to the product in question if this method is to be considered.

Cost

The capital cost for booths, electrostatic spray applicators, and curing ovens is typically higher than similar equipment used for applying conventional fluid coatings. Powder coating systems, however, do not require control equipment to lower VOC emissions.

Powder coating materials are typically more expensive than conventional coating materials on a volume basis. In many cases, however, the cost of producing a finished coating is lower, thereby offsetting the higher cost of the powder.

Because powder coatings can provide a coating of the required thickness in one pass, the economics for powder coatings improves in cases where a thick coating is needed.

For powder coating operations using a single color, maintenance and cleanup costs are low. The operating costs increase for powder coating systems that require frequent color changes. Solvents are not needed; cleanup can be accomplished quickly using only compressed air. No waste solvents are generated and the waste coating material volume is low, reducing disposal costs.

Benefits

The benefits of powder coating systems versus liquid coating systems are:

- Powder does not contain solvents, therefore powder is VOC-compliant. Compressed air, rather than solvent, can be used for cleanup.

- Thick powder coatings can be applied in one pass, even over sharp edges.

- Powder coatings have higher operating efficiencies than conventional coatings. High transfer efficiency results in high material utilization rates.

- Powder coatings require less energy to cure than baking systems

- Because no volatile solvent is used, little air flow is needed in work areas or near curing ovens. The airflow used to contain the powder in the booth can be safely recovered, eliminating the need for make up air. Energy use for heating makeup air declines when air flow requirements are reduced.

- Resins that are not soluble in organic solvents can be used. Powder coatings can coat substrates using polymers such as polyethylene, nylon, or fluorocarbons that are not amenable to solution coating techniques.

- Powder coatings come ready to use and, therefore, do not require mixing or stirring.

Limitations

Limitations of powder coatings may include the following:

- The application of powder coatings requires handling of heated parts (unlike air-dry systems) because the parts must be subjected to elevated temperatures in processing. A cool-down zone is normally required.

- Because powder coatings rely on large, fluidized bed reservoirs, it is more difficult to make color changes than with liquid coatings. Swapping often between a large variety of colors is time-consuming and problems with cross-contamination of color can occur.

- Color matching from batch to batch is difficult.

- Shading or tinting cannot be done by the end user.

- It is difficult to incorporate metal flake pigments that are popular in some automotive finishes in powder coatings. Aluminum flakes have potential for explosion if ignited, although new developments in encapsulating flakes in resin may solve this problem.

- For electrostatic application systems, the parts must be electrically conductive or they must be covered with an electrically conductive primer.

- For electrostatic application systems, parts with complex shapes might be unevenly coated unless special application techniques are used.

State of Development

Powder coating has a well-established niche in the coating industry. Both thermoplastic and thermoset powdered resins are available for use with fluidized bed, electrostatic fluidized bed, electrostatic spray guns or tribocharging spray guns. Detailed information can be obtained from the Powder Coating Institute (see Section 4).

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WATERBORNE COATINGS

Pollution Prevention Benefits

Waterborne coatings substitute water for a portion of the solvent used as the resin carrier in typical organic coatings formulations. In addition to reducing VOC emissions during formulation and application, waterborne coatings pose a reduced risk of fire, are more easily cleaned up (creating less hazardous residues), and result in reduced worker exposure to organic vapors.

How Does it Work?

Waterborne coatings are defined as "coatings which are formulated to contain a substantial amount of water in the volatiles" (Nicholson, 1988). This definition appears fairly vague but it is based on practical considerations. A coating's physical properties are largely determined by the type of solvent carrier. Waterborne coatings contain water as a primary solvent, although substantial quantities of organic solvents can be present.

This definition encompasses a variety of waterborne paints, including emulsions (or latexes) in which only water is used as a solvent as well as water-reducible coatings that incorporate a mix of water and organic solvents. Emulsions are dispersions of resin, pigments, biocides, and other additives in water. Water-reducible coatings are solutions of resins dissolved in solvents; these solvents might be water or a mix of water and organic solvents. Organic solvents are used to aid the solubility of the resins and other additives.

Waterborne coatings have experienced much growth and development in recent years because of concerns about solvent emissions in the workplace and to the atmosphere; waterborne coatings have the potential for zero emissions of VOCs, although many formulations still use some organic solvents. Knowledge of how EPA or state regulations define VOC content is very important. For solvent-borne coatings, the regulations are straight-forward: VOC content in pounds per gallon is measured by the standard test ASTM D 2369-81. This test weighs a portion of coating material, then evaporates off the VOCs and reweighs it; calculating the difference gives the weight of VOC per gallon. With waterborne coatings, most regulations require a VOC content of less than, say, 3.5 lb/gal, less water. This means that to measure the VOC content, the water would first have to be removed, then the standard test procedure should produce a result of 3.5 lb/gal or less in the remaining solution.

Many industries use waterborne coating systems, including building and architecture, automotive, metal finishing, industrial corrosion-protection, and wood finishing. Common perceptions exist in industry that waterborne coatings have inferior properties when compared with their solvent-borne counterparts. For instance, it is commonly thought that all waterbomes take longer to dry than solvent-borne coatings. This is untrue, as many emulsion coatings, especially architectural finishes, dry faster and can be recoated sooner than solvent-bornes. Cured waterborne films are also believed by some to be more sensitive to moisture. Some waterborne automotive topcoats had these problems in the 1980s but many other waterborne systems cure to moisture-impervious coatings.

Waterborne coatings pose less risk of fire and are easier to clean up and dispose of than solvent-based coatings. Because the cost of water is less than that of organic solvents, waterborne coatings generally present an economic advantage. The costs of storage also are lower because waterborne coatings are non-hazardous and do not require storage in flame-proof enclosures. Costs associated with installing ventilation systems in the workplace also are lower.

Waterborne Resin Systems

Waterborne coatings were historically formulated with polymers of high molecular weight and high glass transition temperature to produce a film with good chemical resistance, toughness, and durability without the need for crosslinking in the film. The glass transition temperature is an important concept; it is defined as the temperature at which there is an increase in thermal expansion coefficient (Wicks, et. al., 1992). Often the coating is brittle below this temperature and flexible above it, but this is not always the case. High molecular-weight polymers require solvents to reduce viscosity to acceptable levels and to enable the polymer to soften and flow for good film formation.

Today, formulations with lower molecular-weight resins and lower viscosity are more common. These formulations provide a reaction mechanism for cross-linking between the polymers to achieve desired film properties. A crosslinked polymer generally produces a film with enhanced physical and chemical properties compared to a non-crosslinked film. Cross-linking can be achieved by curing one-component systems at ambient or elevated temperatures, or by mixing two reactive components (two resins or resin plus catalyst) in two-component systems.

Almost all types of resins are now available in a waterborne version, including vinyls, two-component acrylics, epoxies, polyesters, styrene-butadiene, amine-solubilized, carboxyl-tenninated alkyds, and urethanes. Each of these resins has different properties that challenge users to define their needs and coating manufacturers to provide the optimum coating to fill those needs (Pilcher, 1988).

Types of Waterborne Coatings

The three classes of waterborne coatings are:

- Water-soluble or water-reducible coatings
- Colloidal or water-solubilized dispersion coatings
- Latex or emulsion coatings

Water-Soluble Coatings-Resins for water-soluble coatings can be solubilized in pure water or in water-solvent mixes.These coatings are termed “water-soluble” or “water-reducible” because the resin is dissolved primarily in water, and addition of water reduces the viscosity of the coating. Polymers that solubilize in coatings containing only water must be hydrophilic, that is, they must be attracted to and wetted by water. The presence of polar groups on the resin molecule produces hydrophilic polymers.

Water-soluble formulations include water-soluble oils, polybutadiene adducts, alkyds, polyesters, and acrylics. Water-soluble coatings tend to have simpler formulations than emulsions and are easier to apply but have lower durability and lower resistance to solvents (Paul, 1986).

Colloidal Coatings-A colloidal or water-solubilized dispersion coating is an intermediate between water-soluble and emulsion coatings, combining resin systems from each.

The application and physical characteristics of colloidal dispersions lie in between water-soluble and emulsion coatings. Colloidal dispersion or coatings are composed of very fine, partially water-soluble resin droplets dispersed in water. Colloidal dispersions are used mainly to coat porous materials such as paper or leather.

Emulsion or Latex Coatings - An emulsion coating contains resin dispersed as a solid in water. In this case, since the resin is not dissolved it is not required to be hydrophilic, nor is organic solvent required. The droplets are stabilized in an aqueous medium by emulsifiers and thickeners. The most common resin used for emulsion coatings are of the vinyl type, derived from the monomer vinyl acetate. When mixed with other monomers, the coating polymerizes into a film with the desired properties.

Acrylic resins are an alternative binder. These resins are derived from the monomer acrylic acid, which is also the parent monomer for the methacrylates. Acrylic latexes are generally more durable than vinyl acetate copolymers, and they have higher gloss. The two types of monomers, such as a vinyl and acrylic, can be combined to produce films with alternative surface properties.

Emulsion coatings are complex mixtures. Among the ingredients that might be present in the formulation are polymer particles, surfactants, pigments and extenders, thickeners, coalescing solvents, preservatives, and corrosion inhibitors, among others. These ingredients comprise approximately half of the paint formulation; the other half is water. Titanium dioxide is the most common pigment, providing white color and opacity. Since the pigment must be dispersed in the water along with the resin, two dispersing agents are required, one for the resin and one for the pigment. Thickeners or protective colloids must be added to raise the viscosity to a level that is acceptable for application. Preservatives or biocides are added to prevent microorganisms from degrading the additives.

Emulsion coatings are widely used in the building industry, as a decorative and protective coating for domestic houses and other architectural applications. Emulsions dry quickly and additional coats can be applied within a few hours. Tools and containers can be cleaned with water.

The physical and mechanical properties of water-soluble, emulsion and colloidal coatings vary significantly. For example, the handling considerations and performance parameters for a water-soluble with a polymer of molecular weight 2,500 will be different from those of an acrylic latex with a polymer of molecular weight greater than 1 million. Coating systems need to be chosen that will best satisfy all requirements of the application.

The diversity of water-based coating technology is a strength but it also is a challenge. Because water-based coatings provide a range of characteristics, formulations can be prepared to fit many different applications. The waterborne formulations, however, require more careful preparation of substrate and application of coating than conventional solvent-based coatings.

Application Methods

Waterborne coatings can be applied by:

- Brush or roller
- Dip coating
- Flow coating
- Air spray
- Airless spray
- Air-assisted airless spray
- HVLP spray
- Electrostatic spray

All application systems work with waterborne coatings. Waterbornes are very viscous and thixotropic, so spray gun systems must be able to spray the higher viscosity coating. Thixotropy is the extent of shear thinning (degree of liquification) as a result of shear forces in the solution. As with high solids coatings, spray guns may need to be modified (fluid tips replaced, etc.) or new guns purchased. Experimentation can be required to find the best gun for the particular coating that is to be applied. Correct spray viscosity can be achieved by adding water to reduce the viscosity of coating, however, it is better to change spray guns or fluid tips because too much thinning with water will alter the flow and other properties of the coating, potentially causing problems. The applicator should test the guns with the coating material to see if a problem exists, then try different guns and different waterborne coating systems. Spray guns must have stainless steel components where contact with water is an issue.

Some systems such as high-pressure airless and air-assisted airless can be problematic when spraying waterborne coatings. Air bubbles can be generated in the gun and get carried by the coating material to the substrate, becoming entrapped in the surface of the coating. Testing of different spray guns and coating materials should lead to a solution for this problem.

Because waterborne coatings are viscous and thixotropic, they might not be compatible with existing pumps and piping designed for solvent-borne coatings, so new pumping systems may need to be considered.

Electrostatic Spraying-Electrostatic application can be used to raise the transfer efficiency (TE), thereby reducing overspray. Special equipment and techniques are needed for electrostatic application of water-based coatings because of the electrical conductivity of aqueous solutions.

The coating picks up an electrostatic charge in the spray gun nozzle and is attracted to the grounded substrate, resulting in raised TE. Because water becomes easily charged and conducts the charge from the spray gun back to the source of the coating (e.g., container, 55 gal drum etc.), the source must also be isolated from ground. The pressure pod or drum must be kept away from the operator, or a cage must be built to isolate the system and protect the operator. The hose to the spray gun is rubber and must be long enough to reach the distant coating source. At excessive distances, charge can bleed off through the hose to ground.

Four options exist for applying water-based coatings using an electrostatic system (Scharfenberger, 1989):

- Isolate the storage and supply system from electrical grounds to prevent leakage from the application atomizer.
- Use an external charging system that is attached to, but electrically isolated from, the application atomizer.
- Electrically isolate the coating liquid storage and supply system from the application atomizer to prevent current leakage through the coating supply system.
- Place the electrostatic charge on the substrate and ground the application atomizer.

For large waterborne spray systems, a patented solution is available. Developed by Nordson and called the Isoflo system, the system provides solutions to the problem of isolating and caging the coating source, especially if the volume is large and pumps and equipment are large or complicated. This system electrically isolates paint in the spray gun from the paint source, allowing coatings reservoirs and pumping systems to be grounded rather than isolated. Therefore, cages around the coating containers and pumps are not necessary.

In addition to conventional application methods, water-based coatings also are amenable to electrodeposition. Electrodeposition of water-based coatings resembles electroplating where a substrate is submerged in an aqueous bath. The coating material is deposited on the substrate by direct current flow. Electrodeposition is described in Section 2, pages 58 to 61.

Other Issues

Environmental factors such as humidity must be controlled when applying waterborne coatings in order to achieve the best film formation. Too much moisture can prevent curing; too dry an atmosphere can cause very rapid curing, resulting in poor film formation. Humidity can be controlled in spray booths with a microprocessor-controlled water-spray system.

For product finishing, coatings need to dry or cure at elevated temperatures to assure complete cure in a reasonable period of time. Ovens are used for baking waterborne coatings and these have different requirements from ovens used in solvent-borne baking. Lower temperatures will be used and ovens may need to be relined with stainless steel. A stainless flue is especially important to conduct moisture away from the *oven.*

Dry-filter spray booths will need new or modified filters to cope with waterborne systems. Water-wash spray booths require new chemicals in the water to help dissolve waterborne solids.

Pretreatment or cleaning of the substrate is vitally important with waterborne coatings, for similar reasons to those of powder coating and high solids. Waterbornes contain little or zero organic solvents which can wet grease effectively. Water has a high surface tension and grease spots or other contaminants will cause defects in the film unless they are removed prior to coating. Aqueous degreasing systems and abrasive blasting are pretreatment techniques that can clean surfaces in preparation for coating. See for example U.S. EPA (1993), Mounts (1993), Wang and Merchant (1993) and Lehr (1991).

Required Skill Level

Although the application equipment is similar, greater operator skill and attention is needed for application of water-based coatings.

Applications

Water-based coatings are used primarily as architectural coatings and industrial finish coatings because these paints are easy to apply and adhere to damp surfaces, dry rapidly, and lack solvent odor. More than 70 percent of architectural coatings are water-based paints. Water-based architectural coatings include:

- Industrial protective coatings
- Wall primers and sealants
- Interior flat and semigloss wall paints
- Interior and exterior trim finishes
- Exterior house paints

Water-based coatings have not been readily accepted in the industrial sector. Stricter regulations, however, are increasing demand for both primer and topcoat industrial finishes.

Architectural-Water-based epoxy coatings provide excellent adhesion when applied to green or damp concrete. Odor levels during curing of water-based epoxy coatings is low, and the cured coating surface is easy to clean. Water-based epoxy coatings, therefore, are suitable for sanitary areas, such as hospitals or food processing plants (Richardson, 1988).

Development of exterior waterborne gloss enamels has progressed in recent years, although these enamels cannot match solvent-borne enamels in all areas. A recent study (1989) found that waterborne exterior enamels are inferior with respect to gloss, flow, brushability, and opacity. Waterborne enamels, however, are superior in gloss retention, chalking and adhesion (Hayward, 1990).

Products Finishing-Wood products traditionally have been coated with solvent-borne nitrocellulose lacquers, such as clear coatings used on furniture. These lacquers are fast drying and easy to apply with an excellent appearance and hardness, but they have high solvent contents. A waterborne, low solvent nitrocellulose-acrylic latex (NC-A latex) is available. This product, designated CTG D-857 and produced by Aqualon Inc., of Delaware, contains no organic solvent carrier, although small quantities of plasticizers, coalescing solvents and other resins are added to aid in film formation. VOC levels are 2.3 lb/gal or lower. NC-A latex coatings have better clarity, resistance to alcohol, and strippability than acrylic-based latexes. NC-A formulations have lower gloss when applied than acrylic-based latexes, but gloss levels increase after rubbing and polishing (Haag, 1992).

Plastic products have traditionally been difficult to coat with latexes. Since the surface tension of water is higher than the surface tension of most plastics, wetting of the surface and hence film formation is poor. Reducing the surface tension of the coating with surfactants can help, but does not guarantee wetting or adhesion. Polymer chemists have found that by matching surface energy profiles, the coating polymer and plastic substrate can be improved. Waterborne systems are available that meet appearance and resistance requirements of the automotive industry. The computer and business machine industries in Silicon Valley, California, have been using waterbornes on plastics since the early 1980s.

Industrial Applications - Waterborne coatings for coil coating operations are commercially available. These coatings are based on polyester or acrylic resins that are cross-linked with a water-soluble melamine derivative during baking. The complex copolymers that result produce films that can stand up to the rigors of the coiling manufacturing process and later finishing operations (Nicholson, 1988). About 10 percent of U.S. aluminum coil lines use acrylic-based waterborne coatings. Acrylics offer good adhesion, good exterior durability, are resistant to yellowing and are flexible. Epoxy esters also offer good adhesion and are resistant to corrosion and detergents but degrade on exposure to UV. Polyesters, on the other hand, are not resistant to detergents but provide good exterior durability. Alkyds have lower performance but also a lower cost.

A low-VOC water-based epoxy primer is available as a two-component system. Unlike most water-based formulations, water is not present in either of the two components. The components are supplied in a 3: 1 volume ratio and mixed prior to application. Water is added to the mixture to reduce viscosity. After mixing, the formulation contains about 340 g VOC/l (2.8 lb/gal) (MP&C, 1988).

New Developments

A series of coatings developed by ICI Mond Division Laboratories are now available for corrosion protection applications on structural steel. Called Haloflex, the coatings incorporate copolymers of vinylidene chloride, vinyl chloride, and alkyl acrylate or methacrylate with a small amount of acrylic acid. The Haloflex resins form a coating film with low permeability to water and oxygen. The fomlulation also is low in surfactants, which reduce water sensitivity that is inherent in conventional latex coatings.

Research has now found that modified styrene-free acrylic binders in latex formulations work better than styrene acrylic dispersion paints for structural steel protection. This technology is not currently available, but might become available in the near future (van der Kolk et al., 1993).

A series of water-soluble epoxies were developed for corrosion protection of steelwork. These coatings can be applied by brush, spray, or dip tank, and can be dried at ambient temperatures to produce an anticorrosive glossy film (Wilson et. al., eds, 1988).

Water-soluble epoxies also have been developed for coating the interior of metal food and beverage cans. These epoxies have been cross-linked by baking with amino resins such as melamine-formaldehyde (Wilson et. al., eds, 1988).

Waterborne coating systems for automotive basecoats are gaining ground, although the application technology for these coatings is complex. Drying, for example, involves infrared (IR) heating and high-velocity heated air. (Modem Paints and Coatings, 1989,79, 38).

A new technology for water-based coatings has been developed that is a great benefit to the wood and furniture finishing industry. “Core-shell” technology provides for a rapid development of coating hardness, improving the early and ultimate print and block resistance. These properties allow parts to be handled and stacked sooner after coating.

Ecopaint: a Complete System

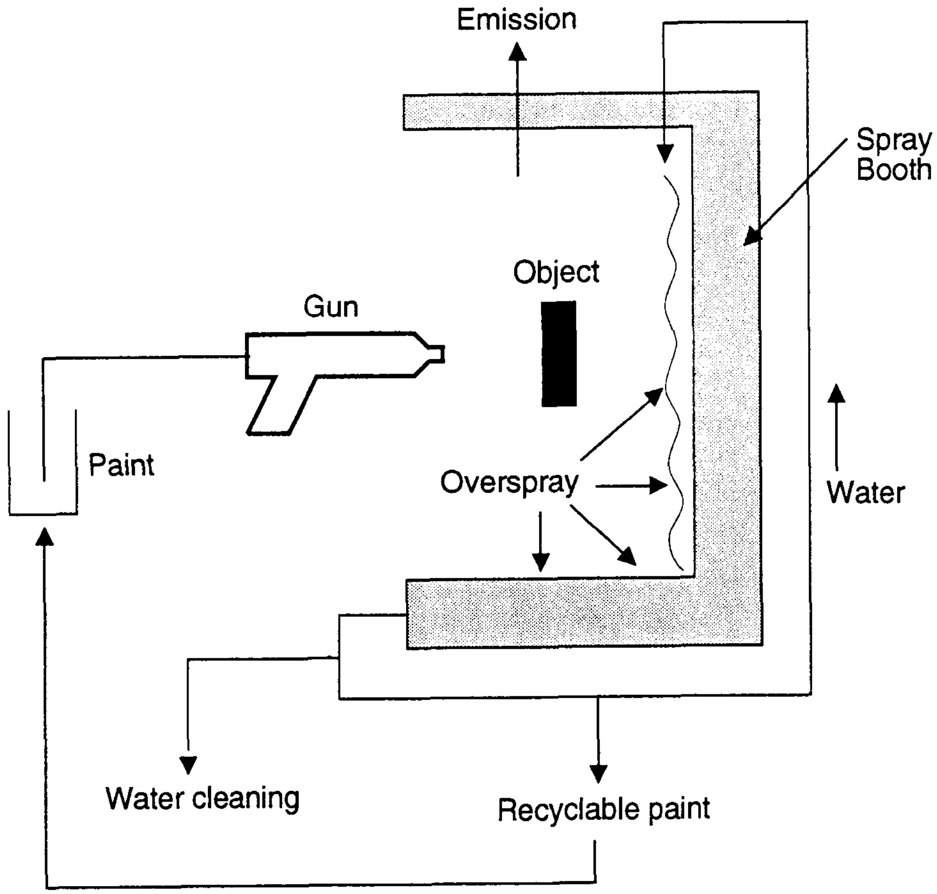
The Ecopaint waterborne paint system was developed in Europe by a consortium of manufacturers to meet strict legislative controls on VOCs. The Ecopaint system comprises a fully water-soluble baking enamel, a water-wash spray booth (Figure 5), and an ultrafiltration unit (Figure 6). The spray booth is a water-wash design that traps overspray and collects paint particles in the water. The waste water/particle mixture then passes through an ultrafiltration unit that separates the water from the particles. In principle, all of the overspray and the waste paint from the cleanup of spray guns can be collected and filtered for reuse. Excess coating material from cleanup of the storage containers (cans) also can be recovered.

The Ecopaint system is suitable for coating a wide variety of products, including automotive parts, workshop furniture, steel shelving, steel pipelines, and other parts requiring a stove enamel finish. The coatings offer a range of gloss levels, textured and structural finishes, and a wide range of color. Surface film properties generally are high enough to meet most normal industrial requirements. Ecopaint coatings are marketed in Europe under the trade name Unicolour, and also are available in the United Kingdom and Japan. These coatings will soon be available in the U.S. (JOCCA, 1993).

Ecopaint baking enamels are based on fully water-soluble resins. They contain less than 5 percent VOCs, with some containing only 3 percent. If required, the coatings can be formulated with virtually no organic solvents; only a small amount is needed to modify film properties. Ecopaint coatings can be applied with most spray methods, including conventional air spray, HVLP, airless, and electrostatic systems, including high speed rotary disks and bells. Flash off times are short and conventional baking temperatures are employed so existing equipment can be used.

Figure 5

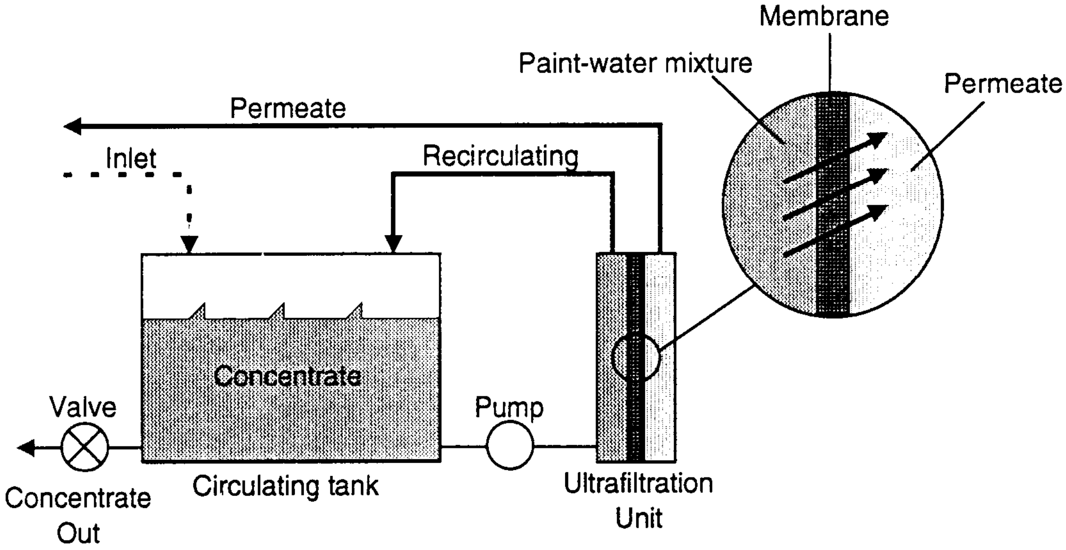
Water-Wash Spray Booth



Source: Eastern Research Group, Inc.

Figure 6

Ultrafiltration Unit for Concentrating Waterborne Enamel



Source: Eastern Research Group, Inc.

Water-based Temporary Protective Coatings

Consumer products, particularly automobiles, are shipped from the factory to the consumer through an uncontrolled and potentially harsh environment. A protective coating helps to maintain the quality of the factory finish.

Temporary protective coatings typically have been solvent-based. These coatings release solvents into the atmosphere on curing, and often require solvents for removal. Temporary coating materials using a water-based acrylic copolymer system can produce a tough transparent film that protects the coating for up to one year. The film can be removed with an aqueous alkali wash solution. Removal of a water-based temporary protective coating takes 10 minutes for an automobile compared to 20 minutes for a wax coating (Product Finishing, 1986).

Water-based coatings also have been tested as masking layers to protect specific areas of metal substrate during chemical milling and etching (Toepke, 1991).

Cost

Water-based coatings are more expensive than conventional coatings per unit of reactive resin. The costs of coating fluid preparation, application, cleanup, and disposal are similar for water-based and conventional coatings. A cost comparison of conventional, powder, high solids, and water-based coatings is presented in Hester and Nicholson (1989).

The capital cost for electrostatic spray systems for water-based coatings typically will be higher than application equipment for solvent-borne coatings because of the electrical conductivity problem. Although water-based coatings typically contain some solvents, they are less likely to require VOC control equipment. High levels of VOC in the waterborne formulation may require carbon absorber equipment or VOC incineration equipment; both are expensive.

Benefits

Because water-based coatings uses less or no organic solvents, problems such as environmental, odor, and safety and health concerns are reduced. The benefits of water-based coatings are:

- Compliance with VOC regulations (though not automatic - compliance depends on actual VOC levels and limitations).
- Less exposure to harmful organic vapors in the workplace. Less need for ventilation systems to ensure safety and/or meet OSHA requirements.
- Lower risk of fire from ignition of organic vapors.

- Do not cause skin irritation from solvent contact

- Good to excellent surface properties including excellent gloss, rub resistance, anti-sealing effect and non-yellowing film.

- Cost savings, depending on the application.

- Clean up and disposal is simpler than with solvents and solvent-borne coatings. Water is primarily used to wash up.

- Existing equipment (nonelectrostatic) can be used for application of most water-based coatings, although stainless steel inserts are required.

Limitations

The drawbacks of water-based coatings are:

- Some waterborne coatings still contain organic solvents (VOCs), though usually less than high solids formulations.

- The flash off time may be longer than for solvent-based coatings. This depends on the formulation and environmental conditions.

- The film has a tendency to be sensitive to water with an increased potential for degradation, though not after full cure.

- More energy can be required to force-dry or bake waterborne coatings than solvent formulations because of the high latent heat caused by water evaporation; energy requirements can be as much as four times greater for water-based coatings.

- Waterborne coatings are sensitive to humidity, requiring humidity control in the application and curing areas. Low humidity can cause those coatings to dry extremely fast, resulting in craters in the final film. High humidity can cause very slow drying times, resulting in sagging.

- The quality of the final film is dependent upon surface cleanliness; the high surface tension of water prevents wetting of some surfaces, especially when grease or other contaminants are present. The high surface tension of water also can cause poor coating flow characteristics.

- High gloss levels are often difficult to achieve.

- Efflorescence or a growth of crystals can occur on certain substrates. Plasterboard is commonly affected when water-soluble salts like sodium sulfate leach out of the coating, disrupting the integrity of the final film.
- Water in the coating formulation can cause "flash rusting" of metal substrates. For this reason, most industrial waterbornes are formulated with inhibitors.
- Toxic biocides often are added to kill microorganisms that attack additives such as fatty emulsifiers or defoamers.
- Emulsion coatings do not penetrate porous substrates, such as wood, very well; this assists "good holdout" but can be a disadvantage if lack of penetration prevents good adhesion on old, chalky surfaces.
- Some types of resins degrade in water, reducing shelf life formulations containing these resins.
- Water-based latex coatings are susceptible to foaming because surfactants often are used to stabilize the latex.
- Water in the formulation also can cause corrosion of storage tanks and transfer piping.
- Special equipment is needed for electrostatic application.

Tradeoffs

Many water-based formulations are compatible with conventional nonelectrostatic spray equipment but require special provisions for electrostatic application. As a result, a change to water-based coatings can be somewhat less disruptive than a change to other technologies such as powder coating.

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ELECTRODEPOSITION

Pollution Prevention Benefits

Electrodeposition uses waterborne coatings with reduced levels of VOCs. The reduced VOC content of the coatings, combined with the superior transfer efficiency of the process, results in reduced VOC emissions. In fact, closed loop operation (which would eliminate VOC emissions completely) is possible with electrodeposition. In addition, because of the higher transfer efficiency there is less waste generated from the coating operation in comparison with conventional coatings operations.

How Does it Work?

Electrodeposition of paints, also known as electrocoating (or E-coat), has existed since the 1920s when the first processes were patented. Electrodeposition is a waterborne coating technology with excellent pollution prevention potential because of the very low organic solvent content and very high transfer efficiency. The automotive industry is the hugest user of electrocoat, priming car bodies for corrosion-protection and subsequent painting. Electrocoating was commonly used in industry in the 1960s with anodic electrodeposition (AED) but, by the mid-1980s almost all of industry was using cathodic electrodeposition (CED) because of superior film properties.

In electrodeposition, the substrate is immersed in a tank filled with coating resins and pigments dissolved or dispersed in water. The substrate must act as an electrode, and, therefore, must be metallic; in practice, steel is the most common material coated. The substrate is connected to a power supply that provides a voltage between the substrate and another electrode which is also immersed in the electrocoating tank (see Figure 7). The electric potential between the electrodes causes a current flow that results in electrodeposition of charged resins and pigments onto the substrate. When the coating process is complete, the substrate is removed from the tank and rinsed; elevated temperatures then are used to cure the coating.

Electrodeposition technology employs a process known as electrolysis that involves both electrophoresis and deposition. Electrophoresis describes the movement of the charged coating particles in solution toward the substrate, deposition occurring when resins and pigments are deposited on the substrate.

Aqueous systems are necessary for electrocoating because the solvent needs to have a high dielectric constant to charge the resin particles. Water, unlike most organic solvents, has a high dielectric constant.

Operating Features

Resin Systems

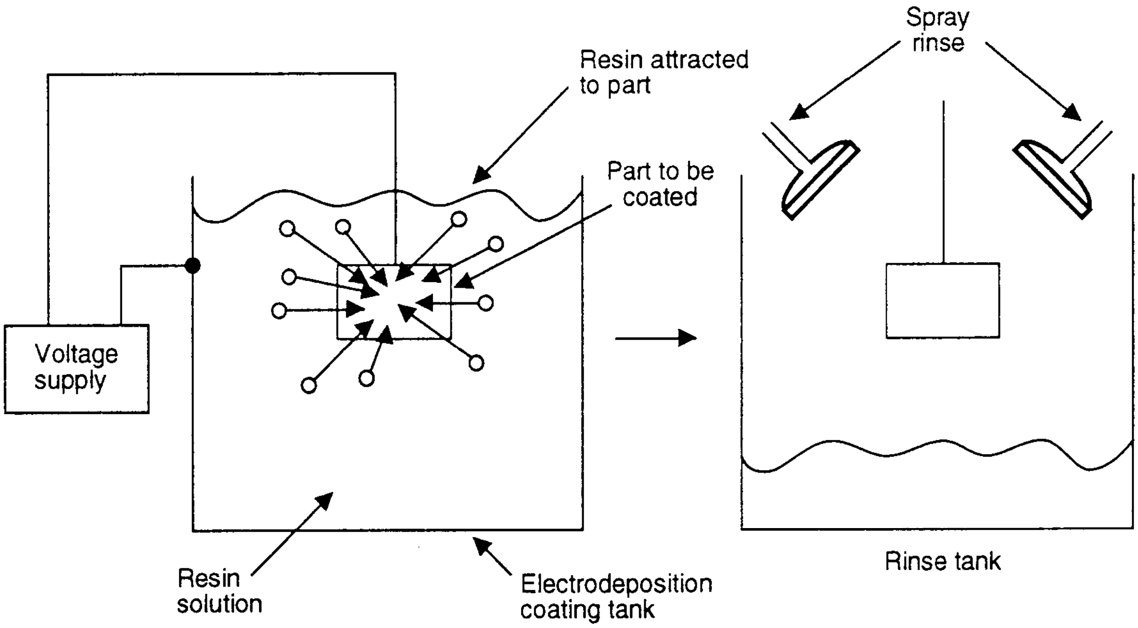
Electrodeposition resins must be able to pick up a charge in solution. Therefore, resins must contain cationic or anionic molecular groups, depending on the polarity of the electrodeposition system. For AED systems, resins generally contain free or neutralized carboxylic acid groups. For CED systems, film-forming cations can be obtained as organic substituted ammonium macro-ions such as RNH3- or R3NH+ (R denotes the resin). Resins with molecular weights in the range of 2,000 to 20,000 are typically used for electrodeposition of water-based coatings.

Many different resins are available for electrodeposition. All resins have three common properties: (I) they can be rendered soluble; (2) made elastomeric; (3) and crosslinked. Amino-containing resins include acrylic and methacrylic esters, styrene, vinyl ethers and vinyl esters with unsaturated monomers that contain secondary or tertiary amino groups. Epoxy-based resins are most commonly used for electrocoating because they have excellent corrosion resistance. Epoxy groups containing copolymers (e.g., glycidyl methacrylate) can react with arnines to form the amino groups necessary for cationic behavior.

Electrocoats contain pigments and extenders along with resins. These materials must be deposited on the substrate at a similar rate or the proportions of pigment/extender to resin in the bath will change over time, causing uneven formation. Careful formulation of the coating prevents these

Figure 7

Electrodeposition



Source: Eastern Research Group, Inc.

problems. Pigments undergo electrophoresis because they adsorb resin molecules on their surface, effectively forming a cation or anion out of the uncharged pigment particle. The cathodic process (CED) is more successful than AED because of superior corrosion resistance and throwing power at low film thicknesses. Most automotive coating plants today use CED.

Application Methods

Substantial amounts of equipment are necessary for applying electrocoats resulting in high installation costs. A dip tank is required that contains the anode (or cathode for AED). A power supply and rectifier also are required; for large automobile body coating tanks, power supplies of 200V to 500V and up to 1500A are necessary. Other required equipment includes water rinse facilities, extra-clean application and curing areas, and ultrafiltration units and baking ovens. Coating large numbers of similar parts is the only way to justify the costs of installing electrodeposition equipment and providing operators with the required training.

Applications

Electrodeposition systems are used most commonly for applying automotive primers because of their high ability to provide very thin, evenly spread films for corrosion protection regardless of the shape of the substrate. Uniform coating can be achieved on substrates with recesses, tapped holes, and sharp edges. By “forcing” a dense film against a substrate, electrodeposition provides excellent adhesion and resistance to corrosion. Small metal parts can be coated in a dip tank. Other parts, such as auto bodies, auto wheels, appliances and other industrial products with high volume runs may be attached to a conveyor and coated in a line process. Electrodeposition can be applied to galvanized steel surfaces, as well as aluminum and other metals.

Benefits

The electrodeposition process is successful in industrial applications for **a** number of reasons:

- Good edge protection and uniform coating thickness.
- High coating utilization (greater than 95 percent).
- An application process that is easy to automate and control.
- Low levels of organic solvents and pollution because it uses waterborne coatings.
- A closed loop process is possible, reducing the potential for pollutants to escape.

Limitations

- Electrodeposition systems have high capital expense
- Electrodeposited coatings are highly sensitive to contaminants.
- To produce a high gloss finish, the coating must contain a conductive pigment.
- The metal substrate can dissolve into the coating, causing discoloration in anodic deposition.

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ULTRAVIOLET (UV) RADIATION- AND ELECTRON BEAM (EB)-CURED COATINGS

Pollution Prevention Benefits

Radiation curing relies on ultraviolet (UV) radiation or electron beam (EB) technology to cure solvent-free coatings formulations. Depending on the formulation and resin type, some VOCs may be emitted from the resins, although these emissions are quite low. Some ***W-*** and EB-cured coating systems emit virtually no VOCs. Organic solvents are still needed for cleanup of uncured coating material, unless the system is based on waterborne finishes.

How Does it Work?

Radiation-cured coatings use radiation from ultraviolet light or electron beam sources to cure solvent-free coating systems. These processes produce high-performance protective and decorative finishes for various product finishes. Radiation curing can avoid the use of solvents entirely, although solvent dilution might be required for some spray applications.

Radiation curing has been adopted by the wood finishing industry (e.g., flatstock tillers in particle boards, hardwood flooring) because of the short cure times and the high quality films that are produced without baking. The graphic arts industry uses UV curing of various printing inks and coatings on paper, cardboard and other substrates.

Radiation-cured coatings usually are sprayed on the object and then subjected to radiation from either ultraviolet (UV) lamps or an electron beam (EB) generator (see Figure 8: ***W*** curing system, and Figure 9: EB generator). The radiation creates free radicals in the coating, initiating crosslinking (or polymerization) of the film. The curing process takes place almost instantaneously when radiation is applied, rather than the minutes, hours, or even days that conventional coatings take.

UV/EB-cured coatings can use 100 percent reactive, liquids, eliminating solvent use altogether. However, certain resins can volatilize and become VOCs, so zero VOC depends on the formulation. UV/EB-cured coatings consist of

> An oligomer or prepolymer containing double-bond unsaturation.
>
> A reactive solvent (e.g., monomers with varying degrees of unsaturation).
>
> A photoinitiator to absorb the UV/EB radiation.
>
> Pigments/dyes and other additives

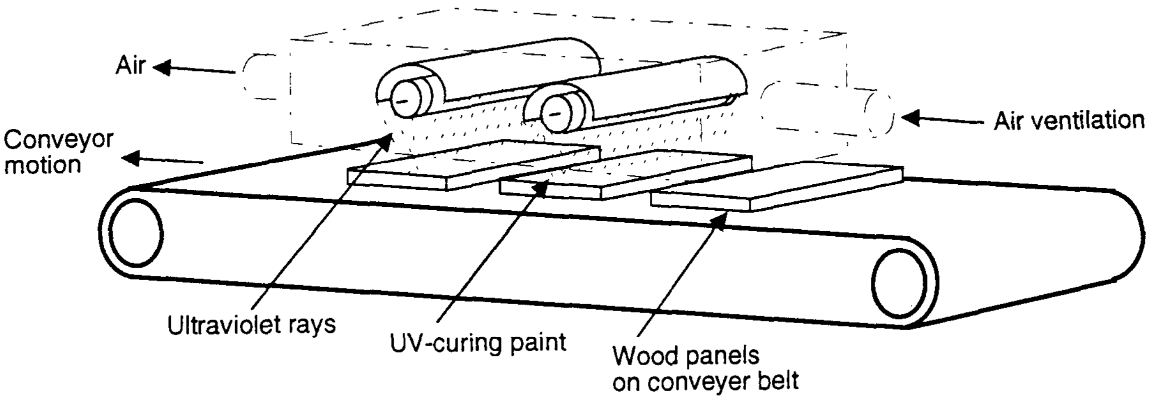
Radiation Chemistry

The first type of radiation-cured coatings to become available used free-radicals in the polymerization process. Free-radicals are highly reactive molecules containing an unpaired electron. They are produced when photoinitiator molecules undergo photochemical reactions on exposure to ***W*** light or EB radiation. Free-radicals react with activated double bonds from acrylate groups, activating a chain reaction that causes polymerization.

During the 1980s a second type of photochemical reaction known as cationic polymerization emerged for use with radiation-curing. This process uses salts of complex organic molecules to initiate cationic chain polymerization in resins and monomers containing expoxides (oxirane rings). ***W*** radiation is the most efficient method of creating the cationic intermediates; EB radiation can be used but is inefficient and expensive. Acrylic alkene double bonds and the oxirane ring can be activated directly by ***W*** radiation without use of a photoinitiator, but this method is much less efficient.

Figure 8

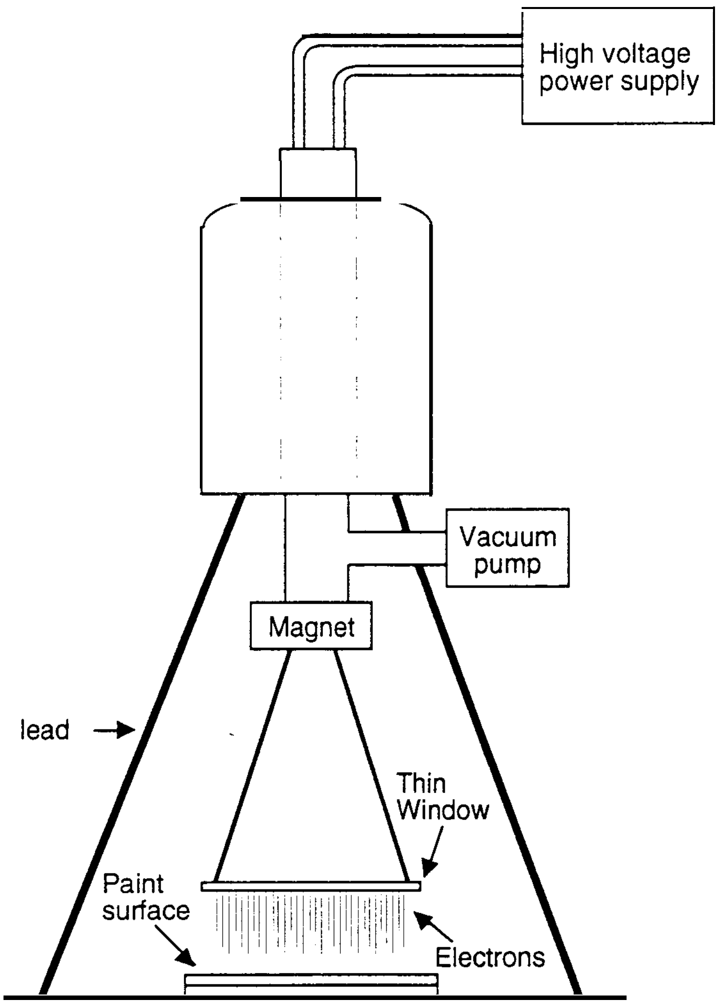
Ultraviolet Curing System



Source: Eastern Research Group, Inc.

Figure 9

Electron Beam Generator



Source: Eastern Research Group, Inc.

Operating Features

Resin Systems

Resins used in conventional solvent-based coatings can be chemically modified for use in radiation-cured chemistries. Resin types include epoxide, polyester, polyurethane, polyether, and others that are modified by introducing acrylate functionality, typically by reacting acrylic acid with alcohol groups **or** hydroxyethyl acrylate with acid groups.

The general physical and chemical characteristics of the resins are retained after modification. Crosslinking of the polymers in the coatings yields excellent chemical and physical resistance. Polyester acrylates exhibit excellent properties in wood and paper coatings. Urethane acrylates can produce films that are tough and abrasion resistant or soft and flexible. The additional chemical reactions that are needed to produce a functional radiation-curable resin, however, add to the cost, hindering the acceptance of UV/EB coating systems (Holman, 1992; Sawyer, 1991). Cationic systems that use vinyl ethers, epoxides, and polyols require less chemical modification than acrylates, therefore these resins should be cheaper, although they are more limited in their applications than acrylates.

Radiation-cured systems using acrylates in waterborne formulations such as water-soluble coatings or aqueous emulsions are available. Wood and chipboard water-based coatings have successfully used acrylates, although gloss and coating resistance is lower than with solvent formulations. High coating specification requirements limits the application of waterborne products in other industries.

Application Methods

Coating material is applied to the substrate by spraying, and is subsequently cured with UV- or EB-radiation. Because curing takes place so quickly, it is advisable to allow a sufficient amount of time between application and curing for the coating to flow-out and achieve maximum gloss. If this is not possible, other precautions and equipment should be considered for use in achieving the desired gloss level (Sun Chemical, 1991). During this flow-out time, emissions of VOCs could conceivably take place.

Radiation Sources

The radiation source most commonly used in industry is the medium-pressure mercury-electrode arc lamp. These lamps, together with high voltage power supplies, are compact and inexpensive and have lifetimes of thousands of hours. The lamps can be retrofitted easily to existing production lines, but they require an extraction system to remove excess heat and ozone that is generated by ***w*** action on oxygen in the air. A disadvantage of the lamps is a prolonged warm-up period that prevents on/off operation; lamps that are modified by doping with metal ions to change spectral characteristics also have a shorter working life.

An alternative type of lamp produces radiation through microwave excitation of the mercury vapor. These lamps are more expensive, but they have the advantage of instant startup/shutdown capabilities. Further spectral modification of the lamps by metal ions does not reduce their working life.

Electron beam generators are expensive, complex and large. These factors inhibit their more widespread use in radiation curing. In addition, oxygen has an inhibiting effect on free-radical polymerization that is initiated by EB, thus an inert atmosphere of nitrogen, with oxygen concentrations of less than 100 ppm is required if adequate curing is to be achieved with EB generators (Holman, 1992). The high capital cost of EB curing equipment has limited the acceptance of EB-cured coatings (Paul, 1986).

Radiation-curing technologies have lower energy requirements for curing compared to conventional solvent or waterborne coating systems. The heat energy required to evaporate solvents or induce thermal reactions in conventional systems is orders of magnitude higher than the energy used in UV/EB systems. Curing a thermoset acrylic resin with conventional technology, for instance, requires 24 times the energy needed for curing clear lacquer with ***W,*** and 12 times the energy needed for curing a pigmented coating with EB (O'Hara, 1989).

Production Issues

Radiation curing occurs on line-of-sight as UV/EB radiation cannot travel around comers of three-dimensional substrates. Consequently, UV/EB systems are most suitable for flat components such as wood panels and materials found in the graphic arts industries. Recently, 3-D radiation sources have begun to cure substrates with more complex surfaces.

Because radiation-curing is a fast and relatively cool process, inks and coatings can be cured on heat-sensitive substrates such as paper and wood. Coating color and opacity affect the curing rate. Darker and more opaque inks block W radiation and require longer exposure times for adequate curing. Likewise, thicker films and multiple films cure more slowly than thin or single films.

EB curing is not affected by coating color or opacity; electrons penetrate pigmented coatings effectively to cure coatings in short exposure times. The high energy of EB curing provides the highest margin of safety in applications where extractables or low odors are essential. High energy also **ensures** adequate conversion from oligomer to polymer so that very thick films **and** laminating adhesives also can be cured.

Applications

W curing is used in these industrial finishing areas:

- Wood finishing
- Metal decorative coatings
- Automotive coatings
- Wire coatings
- Packaging coatings
- Floor finishing

UV curing has been investigated in the U.S. to replace thermally cured coatings for aluminum and galvanized steel cans; W-cured coatings have hardness and salt spray resistance that last 200 hr to 500 hr. W-cured coatings provide highly cross-linked 10-mil-thick films on both bare and insulated wire that are strong, yet flexible.

At least one company in Japan uses EB curing for metal coil stock. EB has also seen limited use in high-volume printing operations. W curing also offers a low-cost, high throughput alternative for finishing automotive hubcaps and wheel rims.

Liquid acrylic and liquid polyurethane-acrylic W-cured coatings surpass press varnish and water-based coatings in quality and film lamination. Likewise, W-cured coatings have found a market niche in high-gloss vinyl floor coverings, surpassing the conventional urethane coatings in ease of application, and in abrasion, solvent, and stain resistance.

W coatings formulated from polyester styrene resins have been used as filler for chipboard. Although commercially available, the polyester-styrene system has not been applied widely because of styrene’s volatility, and the yellow color of the coating that is produced.

Waterborne UV/EB Coating

Radiation-cured waterborne urethanes are available for the wood finishing industry. Waterbornes range from systems that contain small amounts of water for viscosity-reduction purposes to fully water-soluble coatings **or** latexes. Water-based latexes offer the greatest opportunity for pollution prevention because acrylate diluent monomers are usually not necessary for viscosity reduction in this type of coating. The benefits of waterbornes include:

- Reduced acrylate content (which lowers skin irritancy and odor) and reduces the levels of film shrinkage on cure.
- Increased viscosity control.
- Easy cleanup of equipment and spills with water.
- Possibility of very low film thicknesses with low solids formulations
- Additives such as matting agents are easily added to water-based systems.
- Reduced flammability

Waterborne radiation-cured systems do have some drawbacks, however, including:

- A water flash-off step before curing that often requires ovens or other dryers, higher energy use, and longer application/cure times (thin coatings on wood can result in absorption of the water allowing immediate radiation-curing).
- Certain wood substrates will show a grain-raising effect.
- Reduced coating performance with some substrates or coating formulations

Waterborne UV systems have been evaluated by several authors (Mahon and Nason, 1992; Stenson, 1990) with promising results reported for wood finishing applications. Mahon and Nason identified five outstanding UV-cured sealers and topcoats that meet certain performance criteria. Resistance to cold cracking was the major potential problem reported with these coatings. A radiation-curable urethane polymer was evaluated and tested on oak panels in accordance with the National Kitchen Cabinet Association test procedures. Most of the coating properties rated excellent, with only flow appearance and stain resistance to mustard rating average.

Benefits

UV- and EB-cured coatings have a number of benefits:

- Eliminates or reduces solvent use; virtually no VOC emissions.
- High reactivity, very rapid curing.

- High productivity from rapid curing and instant startup and shutdown.
- Low-temperature processing, which allows for the use of heat sensitive substrates such as plastic.
- Long shelf life of coating materials.
- Stable pot life because most coatings are single-component systems.
- Relatively low capital investments in equipment.
- Good film properties and performance, such as hardness; and improved solvent, stain and abrasion resistance.
- Higher non-volatile content that results in higher gloss, better build, and lower shrinkage.
- Lower energy use because of high efficiency UV/EB systems when compared to thermal ovens.
- Equipment requires less space than curing ovens

Limitations

UV/EB technology has several drawbacks:

- Higher cost coating formulations because of expensive raw materials and smaller volume.
- Line-of-sight curing is limited to flat or cylindrical materials that can be directly exposed to the radiation. Radiation systems for 3-D substrates are being developed to overcome this limitation.
- The presence of pigments reduces penetration by UV light, limiting use in high-build applications.
- Polymers for radiation curing are highly reactive and cam cause skin irritation and sensitization.
- UV/EB curing is not always suitable for porous materials.
- EB systems generally require an inert environment because atmospheric oxygen prevents curing of resins.
- EB curing requires equipment with high capital costs.

- Many systems have relatively high viscosity which causes processing and appearance problems.
- No FDA approval for radiation-cured coatings in direct contact with food.
- Generally more expensive on a per pound basis than solvent-borne products.

Future use of UV/EB coatings depends on development of the following:

- More highly developed ***W*** equipment.
- New products/markets for radiation processing technologies.
- New 100 percent reactive monomers and oligomers that are nontoxic and low in viscosity.
- New monomers, oligomers, and polymers that better adhere to metal substrates.
- Lower cost materials

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SECTION THREE
EMERGING TECHNOLOGIES

Introduction

This section on emerging technologies describes coatings systems that are newly available. "Emerging" in this context refers to innovative technologies that have just recently become commercially available and accepted for use in the marketplace. These technologies are less well known than conventional alternatives.

Emerging technologies should not be confused with technologies presently in research laboratories, or those being reported in scientific papers; such technologies are not yet available for industry consumption. These technologies could be termed "developing technologies." Knowledge of developing technologies is important for coatings applicators concerned with improving cost or quality competitiveness, technical performance, environmental improvements, etc. when these technologies become commercially available.

Developing and emerging technologies are not confined to innovative technologies alone. Waterborne coatings are an example of a well established organic coating which is, however, one of today's most dynamically developing technologies. High performance waterborne coatings that are under development or emerging in the market are now able to perform the functions of traditional solvent-borne coatings (such as automotive topcoats). High solids coatings also are under development that will greatly reduce VOC levels while maintaining good performance. The coatings user should not ignore coating types (e.g., waterborne) based on past experiences with earlier versions of the technology. The high rate of technological change results in products that can fill a new performance niche in a very short space of time.

Coatings Literature

To monitor developments in technologies for organic coatings, applicators need to read current literature, i.e., trade magazines or scientific journals. Good reference journals and magazines include:

- ***Journal of Coatings Technology***
- ***Surface Coatings International***
- ***American Paint and Coatings Journal***
- ***Modern Paint and Coatings***
- ***Metal Finishing***

In addition, proceedings from scientific conferences can provide access to information about the latest in research. An example is the proceedings of the ***Pollution Prevention Conference on Low- and No-VOC Coatings Technologies*** (EPA-600/R-94-022, February, 1994) that was sponsored by the U.S. Environmental Protection Agency.

Recently published books can provide insight into the direction of new coatings research. Other sources include trade associations that can direct the applicator to both literature and companies that are researching or developing **new** coatings technologies. A list of trade associations appears in section five of this guide.

Emerging Technologies

This section describes three emerging cleaner technologies for paints and coatings application:

- Vapor permeation or injection-cured coatings
- Supercritical carbon dioxide as solvent
- Radiation-induced, thermally-cured coatings

VAPOR INJECTION CURE COATINGS

Description

Vapor injection curing (VIC) is a newly commercialized process that uses an amine vapor catalyst for rapid coating polymerization (Ballway, 1993; Blundell and Bryan, 1991; Cassil, 1994). Two-component urethane coatings contain a blocked accelerator that is activated during coating application with an amine vapor catalyst. The amine vapor is made by an amine generator in a predetermined concentration and dispersed in an air stream channel in the spray gun. The coating material and catalyst are mixed as they leave the spray gun. This technology is a "high solids" coating system because the coating still uses solvent in the formulation. However, ease of use and production efficiency arising from the rapid cure times provide reasons to use this two-component technology rather than low solids or high solids air or bake coating systems.

VIC can produce a variety of finishes with outstanding urethane performance characteristics, including excellent chemical, solvent, and stain resistance; high humidity and water resistance; high mar and abrasion resistance; and excellent color and gloss retention. Pencil hardness can be achieved in 15 minutes to 45 minutes, with no baking. Dry times can be slashed from 8 hours to 1 hour, without affecting pot life.

The coatings can be used on a broad range of substrates, including plastic, steel, aluminum, wood, and castings. Heat sensitive parts such as thermoplastics and thermosets are ideally suited to the low temperature cure of used with VIC. Other advantages of VIC include increased productivity (resulting from faster handling), decreased operating costs (caused by lowered energy consumption), decreased space for paint curing area, reduced rejects (caused by uncured paint), and reduced recoating and tape time for multiple coats and colors.

VIC is compatible with most conventional, air-assisted airless, electrostatic, and HVLP spray equipment. Electrostatic equipment might need to be modified to accommodate the amine generator. Some types of spray guns might have rubber or plastic seals that degrade when exposed to the amine (dimethylethanolamine). Air-assisted airless spray guns have been used for some time and provide excellent results. The amine catalyst generator is made of aluminum for light weight and mobility, and uses dried and filtered air at 90 psi to 120 psi. Capacity is limited to two spray guns. Some solvent might be required to clean up unreacted resin (Pilcher, 1988).

REFERENCES

Ballway, Bill. 1993. Vapor injection technology for no-bake curing of urethanes. ***Metal Finishing,*** January, p. 62.

Blundell, D., and H. H. Bryan. 1991. Vapor injection cure of two pack polyurethane. ***Journal** of **the Oil Chemists and Colourists Association.*** 1991(3):98

Cassil, Linda. 1994. New technology speeds curing of urethanes. ***Metal Finishing.*** May. pp. 33-35.

SUPERCRITICAL CARBON DIOXIDE AS SOLVENT

Description

Supercritical CO, fluid can be used to replace organic solvents in conventional coating formulations. Union Carbide has developed a system, marketed under the trade name UNICARB, which replaces organic solvents for many liquid coatings. Supercritical carbon dioxide is CO, gas that has been heated above its critical temperature of 88°F and then compressed to approximately 1100 psi until its density approaches that of a liquid. This fluid is similar in character to organic solvents and can be used to replace solvents in paint formulations, reducing VOC levels by up to 80 percent. The CO, solvent is compatible with high molecular weight resins and existing painting facilities and procedures, enabling finishers to use solvent-borne resin formulations while substantially reducing VOC emissions.

Application of Supercritical CO, solvent coatings requires investment in new equipment for paint mixing, handling, and spraying. Supercritical CO_2

proportioning and supply units are available from at least one commercial supplier. The unit mixes coating concentrates and CO, to produce a coating with the required viscosity (see Figure 10). The coating then is supplied to a specially designed spray gun. Coating/solvent mixes are applied in the same way as conventional paint (Nordson, 1991).

In 1991, five coating formulators were licensed to develop, manufacture, and market UNICARB systems. These formulators are Akzo (automotive components, furniture), BASF (automotive), Guardsman (furniture), Lilly (furniture, plastics, heavy equipment), and PPG Industries (automotive, heavy equipment) (MP&C, 1991).

REFERENCES

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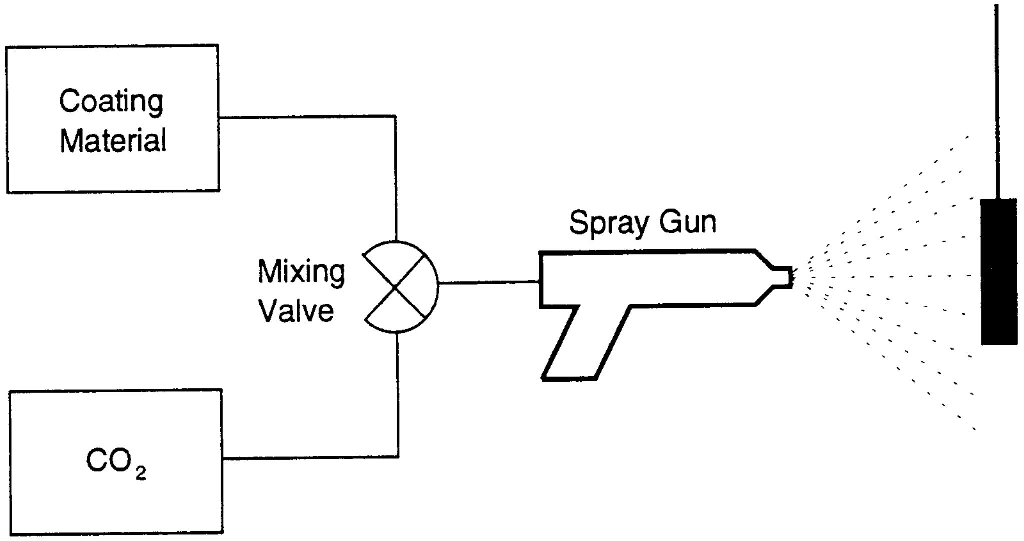
Figure 10

Supercritical Carbon Dioxide Spray Apparatus



Source: Eastern Research Group, Inc.

RADIATION-INDUCED THERMALLY-CURED COATINGS

Description

Infrared, microwave, laser, or radio-frequency radiation can be used to heat a fluid coating and induce curing by thermal mechanisms. The curing reaction is essentially similar to conventional curing in a convection oven, except that heat is supplied by radiation (Paul, 1986; Poullos, 1991).

Laser heating applied by a robotic system produces accurate heat input for rapidly curing thermoplastic or water-based coatings. The laser fusion system originally was designed to cure fluorocarbon thermoplastics such as polytetrafluoroethylene. Curing of other powder and water-based coatings is currently being tested.

REFERENCES

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Poullos, Mark. 1991. Laser Curing of Finishing Systems. ***Pigment and Resin Technology. 20(3): 6.*** March.

SECTION FOUR
POLLUTION PREVENTION STRATEGY

Introduction

The organic coatings industry is affected primarily by guidelines or regulations governing volatile organic compound (VOC) content in liquid coatings. VOC regulations are being developed at the federal level by the U.S. EPA for a number of categories of sources under the 1990 CAAA. In addition, regulatory authorities in several states have developed or are developing their own VOC standards. California has long been a leader in regulations to limit solvent or VOC content in organic coatings, and other states have since developed or are developing regulations.

Current VOC standards for coatings vary depending on the particular industry in question. Prior to 1970, the VOC content of most paint was well above 600 g VOC/l (5 lb/gal). Current major industrial paints now are limited to approximately 420 g VOC/l (3.5 lb/gal) of VOC. Stricter legislation in the future will reduce these levels further.

VOC reduction strategies can be pursued by either the coatings manufacturer or the coating user. Manufacturer strategies differ from user strategies. Manufacturers can work on reformulating existing coatings to reduce VOCs; this is commonly done with high solids coatings. Coatings manufacturers also can research or develop new coatings technologies which are inherently lower VOC or zero VOC. Powder coating technology is an example of a zero VOC coatings system. Various waterborne systems may also approach zero VOC or near-zero VOC content. Manufacturers are investigating the possibilities for low or zero VOC technologies to replace present solvent-based coating systems. Their technical and commercial potential is assessed and decisions are made on whether to produce that coating system for sale and where (see, for example, Randall, 1994).

Organic coating users are able to influence pollution prevention through their choice of coating technology and in-house practices. Industries that currently use coatings with high levels of solvents should investigate the possibilities that exist with low solvent, low VOC coatings because of current and future environmental regulations, liability issues, sales potential (consumer demand), advertising possibilities and environmental friendliness. This Cleaner Technologies Guide is directed toward coating users, rather than manufacturers.

Because VOC limits vary from industry to industry, and since the regulations are often in a state of flux, strict compliance methodologies cannot be provided for each industry. Instead, a general strategy is outlined which allows the industry to examine the issues and formulate a plan to move towards cleaner pollution prevention technologies. The strategy is presented as a list of questions which the user would answer.

Strategy

Questions that a coating user might ask include:

1. Examine current product and associated coating.

- Is the performance of the current coating satisfactory?
- Are there other needs not being met?
- What types of performance from the coating are desired?
- What is the product/substrate made of?
- Will the present coating technology suffice or is change necessary or desirable?

2. Examine state and federal regulations.

- What are the current regulations concerning coatings?
- Are there exemptions or certain requirements for your facility?
- What are likely or possible future regulations concerning coatings?

3. Examine alternative coating technologies.

What coating technologies fit the above performance and regulatory requirements?

- Will the technology meet expected future environmental regulations?
- Will application equipment need to be changed?
- What type of drying and curing? Will an oven need to be installed?
- What will happen to production line speed? Will the new coating slow it down?
- How will the size of the labor force change?
- What learning curve will the staff face?
- What type of surface preparation techniques are necessary? Are existing techniques satisfactory?
- Are capital costs for equipment high or low?
- Are operating costs higher or lower?

4. Other factors to consider in changeover:

- What is the impact of a changeover on immediate operations?
- What is the impact on the long-term efficiency of operations?
- What is impact on occupational health and safety?
- What is the potential for reduced likelihood of liability suits?

5. Search for information.

- Where to find information on these technologies?
    - vendors
    - trade associations
    - state regulators/technical assistance centers

- federal regulators (EPA, OSHA)
- environmental information clearinghouses
- environmental groups

Particular Technologies

A number of coating technologies are already known to have very low or zero VOC emissions and these can be recommended to a coating user for further research or possibly immediate use if the technology suits their needs.

Powder Coating

Powder coating has the twin benefits of zero VOC emissions and high transfer efficiency, while still producing a variety of films with excellent properties. Restrictions on the use of powder come mainly from the need to heat the substrate to high temperatures (500^0F) to melt the powder, its applicability to metallic substrates only, and the small sizes of parts that can be placed in baking ovens.

Waterborne Coatings

Many emulsion coatings are formulated with extremely little or zero solvent. Water-reducible coatings usually contain some solvent but less than high solids coatings. Some water reducible coatings allow overspray to be recovered and recycled, effectively raising the transfer efficiency. Electrodeposition technology is not only zero VOC, but has a very high transfer efficiency as well, making greater use of the coating.

High Transfer Efficiency Spraying

This technology can be readily applied to most, if not all, spray shops using liquid or powder coatings. Powder spraying by electrostatic or tribocharging is already inherently efficient, however improvements may be made by organizing and orienting the parts for greater coverage. The transfer efficiency of liquid coatings can be increased greatly if the current spray system is a high pressure air spraying apparatus (see, for example, Ewert et al. (1993); van Bieman and Oldenburger (1993)). Electrostatic spraying apparatus is available for both solvent-borne and waterborne coatings. Airless and air-assisted airless systems tend to have higher transfer efficiency than high pressure air. High volume, low pressure (HVLP) spray apparatus increases transfer efficiency by reducing the velocity of the coating so that less coating “bounces” off the substrate. Rotary bells and disks, combined with electrostatic charge allow efficient atomization and transfer of coatings, especially high solids. Transfer efficiency can also be raised by reclaiming coating material that has not successfully adhered to the substrate. Powder reclamation systems are available commercially, and recently systems like “Ecopaint” with water wash spray booths and ultrafiltration units reclaim overspray of waterborne coatings.

REFERENCES

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SECTION FIVE
INFORMATION SOURCES

Trade Associations

The following is a list of trade, professional, and standard-setting organizations that can provide technical and other support on various issues related to cleaner technologies for the organic coating industry. Readers are invited to contact these associations and request their assistance and to help identify one or more companies that could provide the desired technological capabilities.

American Institute of Chemical
Engineers (AIChE)
345 E. 47th St..
New York, NY 10017
212/705-7338
212/752-3297 FAX

American Society for
Nondestructive Testing (ASNT)
1711 Arlington Lane
P.O. Box 28518
Columbus, OH 43228-0518
614/274-6003
800/222-2768
614/274-6899 FAX

American Society for Testing
Materials (ASTM)
1916 Race St.
Philadelphia, PA 19103-1187
215/299-5400
215/977-9679 FAX

American National Standards
Institute (ANSI)
11 West 42nd St., 13th Floor
New York, NY 10036
212/642-4900
212/398-0023 FAX

American Chemical Society
(ACS)
11-55 16th St., N.W
Washington, DC 20036
202/872-4600
202/872-6067 FAX

American Society for Quality
Control (ASQC)
310 W. Wisconsin Ave.
Milwaukee, W1 53203
414/272-8575
414/272-1734 FAX

Architectural Spray Coaters
Association (ASCA)
230 W. Wells, Ste. 311
Milwaukee, WI 53203
414/273-3430

Association of Metal Sprayers
(AMS)
5 Keats Rd.
Stratford upon Avon
Warwickshire CV37 7JL,
England
(789) 299661

Association of Finishing
Processes of the Society of
Manufacturing Engineers
P.O. Box 930
One SME Dr.
Dearborn, MI 48121
313/271-1500

Association of Industrial
Metallizers, Coaters and
Laminators (AIMCAL)
211 N. Union St., Ste. 100,
Alexandria, VA 22314
703/684-4868
703/684-4873 FAX

European Confederation of
Paint, Printing Ink and Artists'
Colours Manufacturers
Associations (CEPE)
4, ave. E. Van Nieuwenhuyse
B-1160 Brussels, Belgium
(2) 6767480

European Technical Association
for Protective Coatings
(ETAPC)
Rijenlanddreef 19, bus 5
B-2170 Merksem, Belgium
(3) 6463373

European Coil Coating
Association
47, rue Montoyer
B- 1040 Brussels, Belgium
(2)5136052

Federation of Societies for
Coatings Technology (FSCT)
492 Norristown Rd.
Blue Bell, PA 19422
215/940-0777
215/940-0292 FAX

Federation of the Associations of
Technicians of the Paint, Varnish,
Enamel and Printing Ink
Industries of Continental Europe
(FATIPEC)
28, rue St. Dominique
F-75007 Paris, France
(I)48675224

Halogenated Solvents Industry
Alliance (HSIA)
2001 L St., N.W., Ste. 506
Washington, DC 20036
202/775-2790
202/223-7225FAX

International Committee to
Coordinate Activities of
Technical Groups in the Coatings
Industry (ICCATCI)
34, chemin du Halage
F-95540 Mery-sur-Oise, France
(1) 48675224

National Association of Metal
Finishers (NAMF)
401 N. Michigan Ave.
Chicago, IL 606114267
312/1644-6610
312/321-6869 FAX

National Coil Coaters
Association (NCCA)
401 N. Michigan Ave., Chicago,
IL 60611-4267
3121644-6610
312/321-6869 FAX

National Paints & Coatings
Association (NPCA)
1500 Rhode Island Ave., NW
Washington, DC 2000
202/462-6272

National Paint Distributors
(NPD)
701 Lee St., Ste. 1020
Des Plaines, IL 60016
708/297-6400

National Association of Pipe
Coating Applicators (NAPCA)
Commercial Natl. Bank Bldg.,
8th Fl. 333 Texas St.,
Shreveport, LA 71101-3673
318/227-2769
318/222-0482 FAX

National Spray Equipment
Manufacturers Association
(NSEMA)
550 Randall Rd.
Elyria, OH 44035
216/366-6808
216/892-2018 FAX

Paint, Body and Equipment
Association (PBEA)
c/o Martin Fromm and Assoc.
9140 Ward Pky.
Kansas City, MO 64114
816/444-3500
816/444-0330 FAX

Powder Coating Institute (PCI)
1800 Diagonal Rd., Ste. 370
Alexandria, VA 22314
703/684-1770

Radtech International
60 Revere Drive
Suite 500
Northbrook, IL 60062
708/480-9576

Roof Coatings Manufacturers
Association (RCMA)
6000 Executive Blvd., Ste. 201
Rockville, MD 20852-3803
301/230-2501
30l/88l-6572 FAX

Society of Automotive Engineers
(SAE)
400 Commonwealth Dr.
Warrendale, PA 15096
412/772-7129
412/776-2103 FAX

Society of Manufacturing
Engineers (SME)
One SME Dr., P.O. Box 930
Dearborn, MI 48121
313/271-1500
313/271-2861 FAX

Society of Plastics Engineers
(SPE)
14 Fairfield Dr.
Brookfield, CT 06804-0403
203/775-0471
203/775-8490 FAX

Steel Structures Painting Council
(SSPC)
4400 5th Ave.
Pittsburgh, PA 15213-2683
412/268-3327
412/268-7048 FAX

Transocean Marine Paint
Association (TMPA)
Prins Hendrikkade 14
NL-3071 KB Rotterdam,
Netherlands
(10)4134477

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