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Manual

Pollution Prevention in the Paints and Coatings Industry

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U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory
Center for Environmental Research Information
Cincinnati, Ohio

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

This manual, ***Pollution Prevention in the Paints and Coatings Industry,*** funded through the Center for Environmental Research Information, is a pollution prevention guidance manual for processes and waste reduction in paints and coatings industry.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

ABSTRACT

The paints and coatings industry represents a significant source of multimedia pollution through the wide use of solvent-based process materials and the extensive amounts of wastewater generated by the operations. This manual presents recommended practices for minimizing the generation of pollution in this industry.

Regulations emphasizing source reduction of pollutants at the federal, state, and local level, are driving facility operators to investigate the use of alternative cleaning formulations and paint systems. Aqueous degreasers and powder coatings are two examples of efforts to reduce toxic air emissions and control costs associated with the treatment of contaminated effluent.

Many small and mid-sized facilities have few opportunities to take advantage of technology transfer within the industry. The information in this manual can help operators assess operations and processes for pollution prevention options in using "cleaner" technologies and more efficient management practices. Suggestions contained within this manual can guide improvements in quality and efficiency, indirectly impacting prevention in terms of reduced wastes.

The manual has three general sections:

- An overview of the industry and an introduction to pollution prevention for paints and coatings operations;
- Pollution prevention considerations;
- Case studies emphasizing approaches for reducing process waste.

Appendixes provide a list of suppliers of aqueous and semi-aqueous degreasers and equipment, methodology for specified dilution ratio calculations, and a spreadsheet for factoring transfer efficiency considerations into application processes.

The audience for this document are facility operators and managers, manufacturing process managers, painters, and environmental engineers. Small and medium-size facilities that do not have process engineers on staff have much to gain by implementing recommendations in this manual.

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Contents

Page

Contents (continued)

Contents (continued)

Page

Contents (continued)

Contents (continued)

Page

Contents (continued)

Contents (continued)

Contents (continued)

Contents (continued)

Figures

Figures (continued)

Tables

Table **Page**

Tables (continued)

Page

Conversion Factors

Units of measurement used throughout this document can be converted to SI units using the following conversion factors:

To **convert. . .**	**to . . .**	**multiply by. . .**
cubic feet	cubic meters	2.831685×10^{-2}
degrees Fahrenheit	degrees Celsius	$t^{o}_{C} = (t^{o}_{F} - 32)/1.8$
feet	meters	**0.3048**
inches	centimeters	**2.54**
quarts, liquid	to liters	**0.946352946**
pounds	kilograms	**0.45354237**
pounds per cubic foot	kilograms per cubic meter	16.0184634
pounds per cubic foot	kiloPascals	6.895
pints, liquid	to liters	0.473176473
square inches	square inches	6.4516
tons	metric tons	0.90718474
U.S. gallons	liters	**3.785**

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Section 1
Overview

Chapter 1
Introduction

1.1 Pollution Prevention in the Paints and Coatings Industry

Given the wide use of solvent-based process materials and the extensive amounts of wastewater generated by paints and coatings operations, this industry represents a significant source of multimedia pollution. This manual presents recommended practices for minimizing the generation of pollution in paints and coatings operations.

Many facility operators are actively investigating the use of alternative cleaning formulations and paint systems, such as aqueous degreasers and powder coatings, in an effort to reduce toxic air emissions and control costs associated with the treatment of contaminated effluent. These efforts are being driven in part by regulations at the federal, state, and local level aimed at preventing pollution at its source. In particular, the paints and coatings and other industries must achieve compliance with the Clean Air Act and amendments. Along with preventing pollution at its source, companies are increasingly encouraged to limit the generation of waste through recycling and enhanced management practices.

Because of the diversity in the types of paints and coatings operations, many operators of small and mid-sized facilities have few opportunities to take advantage of technology transfer within the industry. The information in this manual should help operators to perform a complete investigation of pollution prevention (i.e., P2 as referred to by government and industry) factors in their processes and to consider using “cleaner” technologies and more efficient management practices.

Additionally, this manual presents numerous suggestions concerning management practices that may appear to have no direct connection with pollution prevention. Nonetheless, many operators in this industry have found that by making improvements in the name of quality and efficiency, additional benefits can be realized in terms of reduced waste.

The manual covers all basic aspects of a paints and coatings operation. Pollution prevention strategies discussed lead both directly and indirectly to waste minimization. The majority of these strategies can be implemented without the need for major capital expenditures. Often by modifying the approach to a conventional practice, considerable waste and cost reduction benefits can be realized.

1.2 The Audience for This Document

As presented, the suggestions in this document are directed primarily to facility operators and managers, regardless of whether their paints and coatings processes are conducted on an intermittent or continuous basis. Nonetheless, the material also is intended for manufacturing process managers, environmental engineers, and painters themselves. Operators of small and medium-sized facilities likely will have the most to gain by implementing recommendations presented in this document, particularly facilities that do not have a full-time paints and coatings process engineer on staff. Most large operations, such as original equipment manufacturers with in-house expertise, already will have systems in place that incorporate most of these strategies. Although many aspects of paints and coatings processes are chemical specific, the vast majority of information presented in this document can be understood and acted upon regardless of whether the reader has a science background.

1.3 The Organization of This Document

This manual is divided into four sections. This first section provides a general introduction to pollution prevention in relation to paints and coatings operations along with an overview of the industry (Chapter 2). The sections that follow address pollution prevention considerations in the context of the basic process flow for paints and coatings operations. Thus, the discussion proceeds from pretreatment stages, such as degreasing and phosphating, to the various methods of paint application. The final section presents a selection of case studies that emphasize approaches for reducing process waste.

Section Two on pretreatment factors begins with a general discussion about the importance of proper adhesion of the coating to the substrate for minimizing pollution in paints and coatings operations (Chapter 3). The chapter introduces the concept of “right-first-time” processing as a management practice that focuses on avoiding reworks of coatings that fail because the workpiece was inadequately prepared to receive a paint system. As described in Chapter 4, a comprehensive approach to ensuring proper adhesion of applied coatings begins with the appropriate handling and storage of raw materials and vendor-supplied component parts.

Chapters 5, 6, and 7 address pollution prevention in regard to the fundamental pretreatment processes of degreasing, phosphating, and rinsing, respectively. For many operations, conventional approaches to cleaning and otherwise preparing workpiece surfaces for coating application generate large amounts of wastewater, much of which must be handled expensively as hazardous waste. These chapters suggest alternative approaches to performing these pretreatment steps that can, for instance, minimize water usage (i.e., by using counter-flow rinsing) and reduce the use of toxic, solvent-based materials (e.g., by using aqueous degreasers). Although degreasing, phosphating, and rinsing often are conducted in an integrated process line, they are addressed separately in this document as a means of highlighting specific best management practices.

The final pretreatment chapter (Chapter 8) addresses pollution prevention in regard to abrasive blast cleaning. A primary consideration is the recyclability of the abrasive media; however, water-use reduction as an incidental benefit of blasting also is addressed.

Section Three on application process factors begins with a discussion of transfer efficiency-of the coating to the workpiece substrate-as a fundamental consideration for pollution prevention (Chapter 9). Of the many strategies recommended in this manual, transfer efficiency improvement is likely to yield the greatest pollution and process cost reductions. Several of the practices discussed can be implemented immediately, without the need for either capital expenditure-or process-line reconfiguration.

Chapters 10 and 11 focus on the two types of coating systems, liquid compliant and powder coatings, respectively, in terms of selection criteria related to pollution prevention. The discussion on liquid coatings, for example, presents a basis for considering the use of coatings that are low in volatile organic compounds (VOCs), while the powder coatings discussion considers appropriate situations for the use of these low-pollutant-generating systems.

Although the pollution prevention benefits of controlling the viscosity of an applied coating are somewhat indirect, the management practices suggested in Chapter 12 can be essential for ensuring right-first-time processing. As this chapter explains, by altering the viscosity of a coating to achieve better substrate coverage for particular workpieces, superior finishes can be achieved, thus minimizing the need for reworks. Several strategies are suggested for maintaining a constant viscosity throughout the application process to improve the consistency of color, gloss, and texture in a coating system.

Chapters 13, 14, and 15 speak to practices that can have a more direct effect on pollution prevention. For example, recommended practices include minimizing solvent usage when cleaning equipment (e.g., through recycling cleaning formulations) and minimizing pollution in spray booths (e.g., by controlling particulate emissions).

Section Four provides case studies that illustrate approaches to addressing typical paints and coating problems (Chapter 16).

Appendixes to the document provide a list of suppliers of aqueous and semi-aqueous degreasers and equipment (Appendix A), a methodology for calculating the rinsing flow rate required to achieve a specified dilution ratio (Appendix B), and a spreadsheet for factoring transfer efficiency considerations into a coating application process (Appendix C).

Chapter 2
Overview of Paints and Coatings Operations

2.1 Introduction

The paints and coatings industry is made up of many different types of operations, ranging from large-volume original equipment manufacturers (OEMs) that run highly automated, closely monitored systems to custom shops performing a range of contract work with manually operated equipment. Nonetheless, because certain basic practices are common to the industry, pollution prevention measures discussed in this document will have relevance for many facility operators.

Throughout this document, pollution prevention considerations are raised in the context of best management practices recommended for individual stages in the paints and coatings process. This chapter introduces those that follow by providing brief descriptions of the general types of operations that constitute this industry. Process-specific terms used in this chapter are explained in subsequent discussions on pretreatment and application processes.

2.2 Operations for Miscellaneous Metal Workpieces

2.2.1 Priming Only

Most manufactured products, or parts included in those products, are not required to receive a coating beyond the primer coating. For instance, a topcoat may be unnecessary if such products or parts in their intended use will never be exposed to corrosive environments. In other cases, the useful life of the product or part may be sufficiently short that applying a finish coat adds little or no value. Additionally, some parts may receive a primer coating in conjunction with the original fabrication, and then they may or may not receive a finish coating when the end-product is assembled. Examples of products and parts manufactured in the metals industries that might receive only a primer coating are listed according to Standard Industrial Classification groups and codes in Tables 2-l and 2-2.

Figure 2-l presents a schematic of a typical process line in which fabricated metal parts receive only a primed coating before being shipped. This type of operation might involve removing surface contaminants such as

Table 2-1. Major Group 33: Primary Metal Industries

SIC Code	Example of Industry
3122-3399	Axles, rolled or forged
	Car wheels
	Railroad crossings
	Sheet steel
	Steel baskets, made in wire drawing plants
	Chain link fencing, made in wire drawing plants
	Spikes
	Steel wire cages
	Wire carts, household, grocery, made in wire drawing plants
	Conduit
	Wrought pipe and tubes
	Cast iron cooking utensils

Table 2-2. Major Group 34: Fabricated Metal Products, Except Machinery and Transportation Equipment

SIC Code	Example of Industry
3411-3499	Shipping containers
	Drums and pails
	Hedge shears and trimmers
	Hand and edge tools
	Saw blades and handsaws
	Fabricated iron and steel brackets
	Fireplace equipment
	Ice chests or coolers
	Ladder jacks
	Trunk hardware
	Bathroom fixtures
	Lawn sprinklers
	Room gas heaters
	Swimming pools heaters
	Radiators
	Wood and coal burning stoves
	Door and jamb assemblies
	Liquid oxygen tanks
	Sheet metal hoods
	Bombs and parts
	Mortar fin assemblies
	Rifles
	Industrial gate valves
	Torsion bars

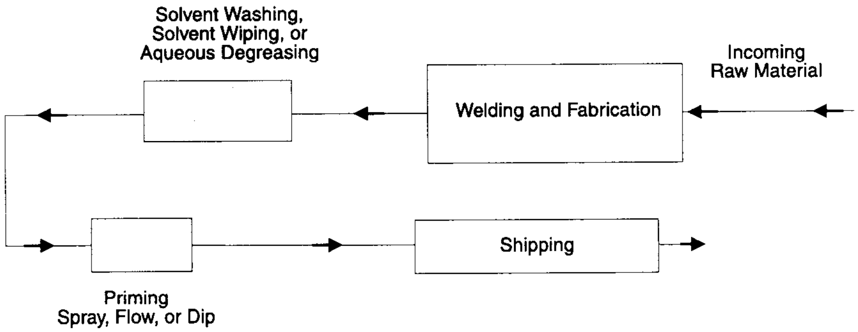

Figure 2-1. Schematic of a typical process for priming metal parts.

oil and grease by washing or wiping the workpieces with a solvent or applying an aqueous degreaser with high-pressure hot water. Because the quality of the surface finish is not critical for such parts and products, the primer coating can be applied either in a dip tank or with a flow coater.

The use of dip tanks involves immersing the workpiece into a vat of paint, after which the piece is suspended over the vat so that excess primer can run off. The flow coating process is similar to dip coating, although the paint is poured onto the workpiece; the piece is then suspended over a collection area so that excess paint can drain and be recycled into the process. An alternative to dipping and flow coating is spray application. Primer-only operations in which spray guns are used tend to be fairly basic, without sophisticated equipment or process-line automation.

Historically, paints and coatings facility operators have used these approaches to apply solvent-borne primers that are high in volatile organic compounds (VOCs). Although such coatings were favored for their extremely fast drying properties, they are known to emit significant quantities of VOCs, of which some also may be hazardous air pollutants and/or ozone depleting compounds.

In recent years, water-borne primer coatings have become available that offer dramatic reductions in VOC content. These can be used for dip, flow, and spray applications. For some operations, however, switching to these alternative formulations may be problematic because they require longer drying times. Moreover, some formulations are highly sensitive to the degree of surface cleanliness. For instance, whereas the cohesion of some solvent-borne coatings might be unaffected by traces of oil and grease on a metal substrate, water-borne coatings might pull away and form craters. Nevertheless, many paints and coatings operations are moving toward water-borne primers because they are less harmful to the environment.

Typically for such operations, process-line operators could benefit from additional training, and abatement equipment for reducing hazardous emissions is somewhat inadequate. Thus, pollution prevention programs can be beneficial.

2.2.2 Priming and Topcoating

Many manufactured products must receive both a primer and a finish coating. Such products might be used in applications in which corrosion resistance is an important, if not critical, property. Also, the value of the product might be significantly enhanced if its useful life can be extended by its ability to resist the assault of corrosive elements. Additionally, the value of countless products can be enhanced by a primer-topcoat system that provides general visual appeal while adding to overall quality and durability. Examples of products in the metals and metals-related industries that might receive a primer-topcoat system are listed according to Standard Industrial Classification groups and codes in Tables **2-3** to 2-7.

Primer and finish coatings are applied either separately or in a single process line, as described below.

2.2.2.1 Priming and Topcoating as a Two-Stage Process

Typically, heavy equipment and machinery (e.g., excavators, army tanks) receive a primer-topcoat system in two stages. In the first stage, the various parts and components of the products are primed. In the second stage, following assembly, the topcoat is applied.

Figure 2-2 shows a schematic of a process in which workpieces receive a primer coating in a first stage, then a finish coating following product assembly. In such a process, incoming raw material often is cleaned (e.g., degreased or steam-cleaned) before being moved along for welding and fabrication operations. This initial cleaning removes surface contaminants that could undermine the integrity of welding bonds on sub-assemblies. After fabrication, sub-assemblies and component parts undergo pretreatment (e.g., additional cleaning) before priming. Once applied, typically the primer is allowed to dry and cure at ambient temperature, although some operations use dry-off ovens. The primed piece then

Table 2-3. Major Group 35: Industrial and Commercial Machinery and Computer Equipment

SIC Code	Example of Industry
3511-3599	Windmills for generating power
	Steam engines, except locomotives
	Engine and engine parts
	Marine engines
	Agricultural implements and machinery
	Blowers and cutters
	Farm elevators
	Greens mowing equipment
	Combines (harvesters and threshers)
	Spraying machines
	Construction cranes
	Road graders
	Logging equipment
	Tractors
	Vibrators for concrete construction
	Mining machinery and equipment
	Elevators and moving stairways
	Conveyors and conveying equipment
	Machine tools
	Power-driven hand tools
	Textile machinery
	Woodworking machinery
	Printing trade machinery

Table 2-4. Major Group 36: Electronics and Other Electrical Equipment and Components, Except Computer Equipment

SIC Code	Example of Industry
3612-3699	Power distribution and specialty transformers
	Switchgear and switchboard apparatus
	Motors and generators
	Relays and industrial controls
	Battery chargers
	Barbecues, grills, and braziers
	Electric dehumidifiers
	Household fans
	Electric wall heaters
	Vacuum cleaners
	Floor waxers and polishers
	Electric wiring boxes
	Electric conduits and fittings
	Residential electric lighting fixtures
	Commercial, industrial, and institutional lighting fixtures
	Household audio and video equipment

may be stored for a time as inventory before it is used in end-product assembly.

Table 2-5. Major Group 37: Transportation Equipment

SIC Code	Example of Industry
3712-3799	Ambulances
	Car bodies
	Fire department vehicles
	Motor homes
	Personnel carriers
	Tractors
	Motor vehicle parts and accessories
	Oil, air, and fuel filters
	Motor vehicle horns
	Exhaust mufflers
	Motor vehicle radiators
	Patrol boats
	Floating radar towers
	Steam engines (locomotives)
	Trolley buses
	Bicycles and parts
	Motor scooters and parts
	Campers for mounting on trucks
	Military tanks
	Trailer hitches
	Wheel barrows

Table 2-6. Major Group 38: Measuring, Analyzing, and Controlling Instruments; Photographic, Medical, and Optical Goods; Watches and Clocks

SIC Code	Example of Industry
3812-3873	Air traffic control radar systems
	Distance measuring equipment
	Gyroscopes
	Hydrophones
	Nautical instruments
	Laboratory balances
	Laboratory hot plates
	Laboratory furniture
	Clothes dryer controls
	Thermostats
	Computer interface equipment
	Differential pressure instruments
	Magnetic flow meters
	Speedometers
	Sparkplug testing equipment
	X-ray equipment
	Photographic developing machines
	Photographic enlargers
	Appliance timers

The component parts of an end-product can become scuffed and soiled during assembly and product testing operations. In many cases, the product becomes sufficiently marred and soiled that it must undergo some surface preparation (e.g., selective scuff sanding, solvent wiping, hot-water spray) before the finish coating is applied. On occasion, surfaces may have become sufficiently damaged overall that the assembled product must be prepped and reprimed either extensively or in selected areas.

Factors that can contribute to the need for remedial preparation before applying a topcoat, unnecessarily generating pollution and adding to costs, include:

- Inadequate initial surface preparation.
- Use of a low-quality primer.
- Inadequate storage procedures (e.g., outdoors and uncovered).
- Improper material handling procedures.

Table 2-7. Major Group 39: Miscellaneous Manufacturing Industries

SIC Code	
3911-3999	Electronic musical instruments
	Music stands
	Games, toys
	Fish and bait buckets
	Exercising machines
	Rowing machines
	Treadmills
	Pen holders and parts
	Artist frames
	Easels
	Stamp pads
	Hand stamps (e.g., time, date)
	Costume jewelry
	Costume ornaments
	Paint rollers
	Street sweeping brooms
	Advertising displays
	Name plates
	Neon signs

As with the primer coating, following topcoat application the finished product is dried either at ambient temperature or in a dry-off oven.

2.2.2.2 Priming and Topcoating as a Single-Stage Process

For smaller products that require little or no assembly before shipping (e.g., wheel barrows, music stands) and for some component parts, a primer-topcoat system is applied in a single process line. Such a process is similar to the two-stage process, except that the painting operation is not interrupted for assembly.

Figure 2-3 shows a schematic of a process in which workpieces receive a primer coating and a finish coating in a single-stage operation. Typically, for such a process the entire operation is conveyorized, from cleaning the incoming raw materials to applying the topcoat. After drying and curing, the workpiece is removed from the conveyor and prepared for shipping or stored for assembly operations.

2.2.3 Surface Preparation

The amount of surface preparation included in paints and coatings operations for miscellaneous metal work-

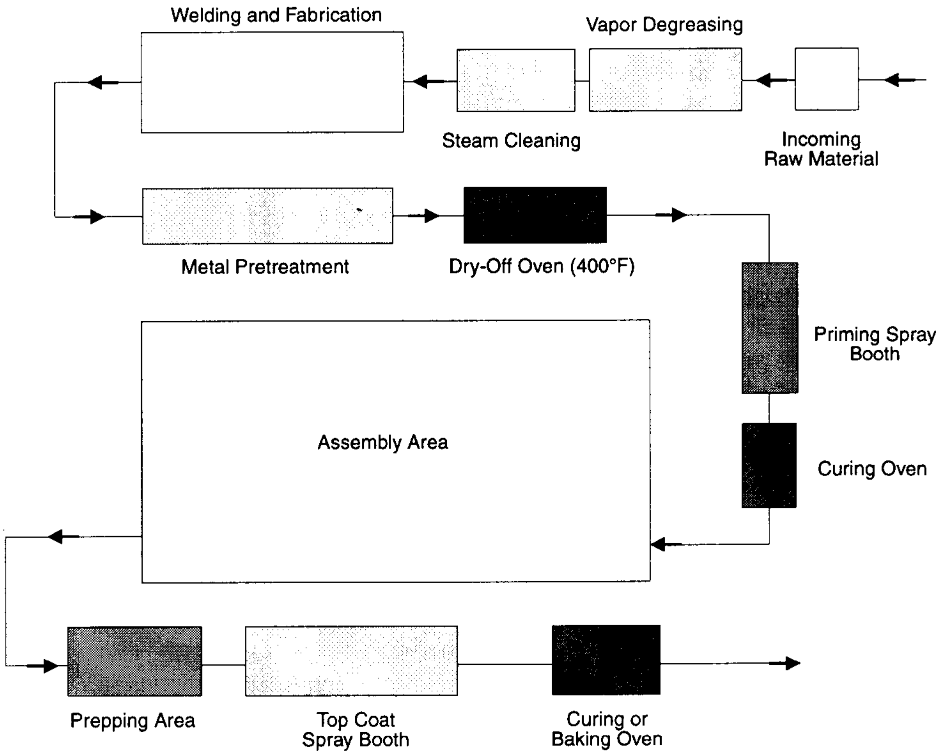

Figure 2-2. Schematic of a process for two-stage application of a primer-topcoat system.

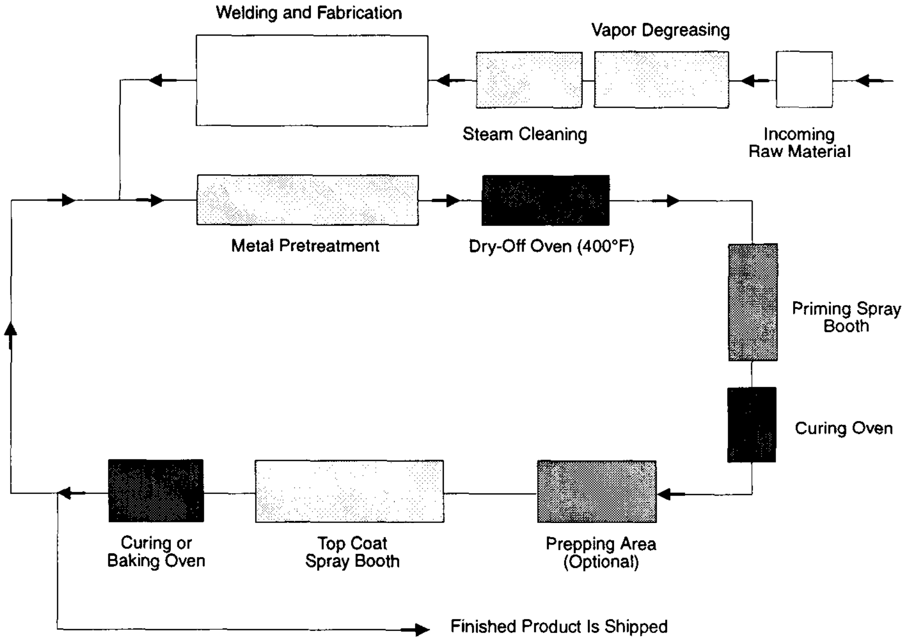

Figure 2-3. Schematic of a process for single-stage application of a primer-topcoat system.

pieces spans a broad range. For example, low-value products for price-sensitive markets may undergo little or no preparation before a paint coating is applied, while metal components for industrial machinery that will be operated in a corrosive environment may receive extensive pretreatment. Typical pretreatments for metal workpieces include phosphating and abrasive blasting, both of which are discussed briefly below.

2.2.3.1 Phosphating

Phosphating (i.e., iron and zinc phosphating) is a process of depositing a conversion coating onto steel or galvanized steel to enhance the paint coating's adhesion to the metal surface. This strengthened bond enhances the coatings' ability to resist corrosion. Typically, iron phosphating is conducted using a three-step process, as shown in Figure 2-4, that includes two rinse steps. To achieve a primer-topcoat system with enhanced corrosion resistance, facility operators often rely on a five-step process, as shown in Figure 2-5, that comprises three rinse steps. Although either iron or zinc phosphate can be used in such a process, usually zinc is specified when superior corrosion resistance is required.

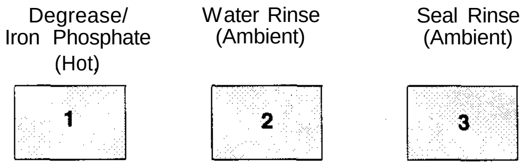

Figure 2-4. Schematic of a three-stage iron phosphating process.

Depending on their size and the volume throughput requirements, workpieces undergo phosphating either in batches by immersion or as individual pieces that are sprayed as they are moved through the process by conveyor. In spray processing, workpieces are transported through the various spray zones. To the extent possible, solutions are captured and recycled.

Chromate oxide formulations should be used to apply a conversion coating to aluminum workpieces. For low-value end-products, aluminum workpieces often are pretreated using an aqueous (i.e., nonchromate) formulation. A typical process for applying a conversion coating to aluminum workpieces with either a chromate or nonchromate formulation is shown in Figure 2-6.

For most pretreatment processes, the phosphating stage is followed immediately by a dry-off oven at a temperature that will evaporate water as quickly as possible, to prevent flash rusting. For ovens used to dry particularly bulky pieces, the temperature may be as high as 400°F.

2.2.3.2 Abrasive Blasting

Abrasive blasting is a method of both cleaning corrosion and other surface contaminants from metal workpieces and giving the substrate a textured profile. The combination of a clean surface and a textured profile enhance coating adhesion, providing corrosion-resistance properties. Facility operators generally opt for this approach when workpieces are too bulky and heavy (e.g., metal frames) to be effectively cleaned and phosphated in spray or immersion processes.

If oil or grease is on the surfaces of the workpieces, the facility operator typically will degrease them prior to abrasive blasting by spraying them to the extent possi-

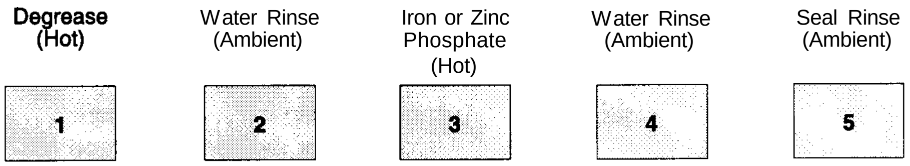

Figure 2-5. Schematic **of a five-stage iron or zinc phosphating process.**

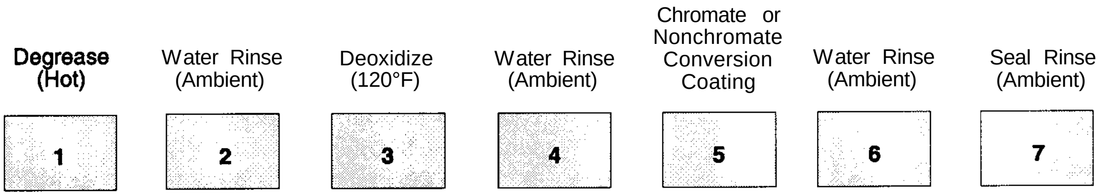

Figure 2-6. Schematic of a typical conversion coating process for aluminum workpieces.

ble with super-heated steam or high-pressure hot water. This minimizes the likelihood that the blasting media will transfer contaminants between workpieces.

2.2.4 Application of Paint Coating Systems

The types of paint coatings and application systems used in paints and coatings operations for miscellaneous metal workpieces also span a broad range. A selected list of paint coatings that includes both water- and solvent-borne systems is presented in Table 2-8. Typical spray and automated applications equipment is listed in Tables 2-9 and 2-10, respectively. Because many paints and coatings operations use spray application, common spray booth designs are listed in Table 2-11. Spray booths in these designs are available off-the-shelf or as custom equipment.

Table 2-8. Typical Coating Technologies for Miscellaneous Metals Parts

Classification	Resin Technology
Water borne (air or force dry)	Alkyd and modified alkyd (water based)
	Acrylic latex
	Epoxy (water based)
Water borne (bake)	Alkyd and modified alkyd (water based)
	Acrylics
Solvent borne (air or force dry)	Alkyd and modified alkyd
	Epoxy catalyzed (two component)
	Polyurethane (single or two component)
Solvent borne (bake)	Alkyds and modified alkyds
	Acrylics
	Polyester (oil free)
Specialized coatings	Autodeposited
	Electrodeposited
	Powder
	Ultraviolet curable

2.2.5 Abatement Equipment

Although emission abatement devices are not widely used in operations applying coatings to miscellaneous metal products, several types of equipment are available. Typical devices are listed in Table 2-12. Indeed,

Table 2-9. Most Common Manual Spray Guns

- Conventional air atomizing
- Air-assisted airless
- Airless
- High volume, low pressure (HVLP)
- Electrostatic (low voltage)
  - Conventional air atomizing
  - Air-assisted airless
  - Airless
  - HVLP
- Electrostatic powder application

Table 2-10. Most Common Automated Coating Processes

- Dip coating
- Flow coating
- Electrodeposition
- Autodeposition (primarily for priming steel)
- Electrostatic turbo bells and discs
- Automatic spray guns[a]

[a] Using any of the delivery and atomization mechanisms listed in Table 2-9, except that electrostatic guns will usually be of the high-voltage type.

Table 2-11. Common Spray Booth Designs

Direction of air flow
Cross draft
Down draft
Semi-down draft
Filtering mechanism
Dry filter
Water wash
Baffle

Table 2-12. Typical Abatement Control Devices for Painting Facilities

Thermal oxidation (regenerative)
Thermal oxidation (recuperative)
Catalytic incineration (regenerative)
Carbon adsorption (alone or in combination with thermal oxidation)
Zeolyte adsorption (alone or in combination with thermal oxidation)
Ultraviolet oxidation
Biofiltration
Membrane
Condensation

indications are that less than 20 percent of paints and coatings facilities operate with abatement equipment for capturing VOC emissions. The use of such devices is low in the industry because most facilities operate below threshold limits established by regulation. These regulatory limits can vary from state to state, or even from one community to another. Relatively few facilities, particularly those with VOC emissions exceeding 100 tons/year, are required by federal, state, or local regulations to abate emissions.

2.3 Operations for the Automotive Industry

2.3.1 Process Overview

Paints and coatings operations for the automotive industry generally differ from those for miscellaneous metals because the finish coating on products must be of superior quality and appearance. Typically, the process for applying a primer-topcoat system in the automotive industry includes multiple stages, as shown in Figure 2-7. Moreover, individual stages in the process can include multiple steps.

For instance, industry standards call for the use of zinc phosphating, which typically is conducted in a multistep process that is closely monitored. Figure 2-8 shows a 10-step phosphating process, typically used in the automotive industry, that includes six rinse steps, half of which use deionized water.

After a car body, for instance, has passed through the phosphating stage, it is immersed in a large electrodeposition tank, in which a cathodic or anodic primer is applied. This electrodeposited primer is then cured in an oven at temperatures ranging from 300^{o} to 400°F. The underside of the body then receives a polyvinyl chloride (PVC) coating that provides sound-proofing attributes. Also, all seams and mating surfaces receive a sealer to prevent moisture penetration.

Next, the car body may undergo light sanding before a primer is applied. In some facilities, a wet-on-wet topcoat also is applied at this point to the underside of the hood and the inside of the trunk. The primer and interior topcoats then are dried and cured in a baking oven, after which the body enters the topcoating spray booth. Depending on the color to be achieved, a solid color topcoat may be applied or a basecoat may be applied followed by a wet-on-wet clearcoat. After topcoating, the car body enters the final baking oven in which the topcoat is cured.

At various locations along the process line, the car body may be moved aside so that line operators can inspect for defects in either the primer or the topcoat. When a defect is discovered, the area is scuff sanded and touched up.

2.3.2 Paint Coating Systems and Application Processes

2.3.2.1 Types of Coatings

During the 1970s the automotive industry made a concerted effort to use water-borne primers and topcoats. These included acrylics, epoxies, polyesters, melamines, and oil-modified alkyds. Most of the pigments were compatible with water-soluble resin systems. Initially, however, problems arose because adding aluminum pigments to these high-pH range (8.0 to 9.0) formulations generated hydrogen gas (1). As a result, specially treated aluminum pigments were manufactured to solve this problem.

Other problems included the requirement that water-borne coatings be applied in highly controlled environments (e.g., temperature ranging from 70^{o} to 80^{o}F, relative humidity ranging from 40 to 60 percent). Also, to prevent rupturing or blistering of the coating, finished parts had to be dried initially in a low-temperature zone (i.e., 150°F) of the oven. Only after all water had been evaporated, could the part safely enter a high-temperature zone (i.e., greater than 250°F).

Later, when basecoat/clearcoat systems providing an enhanced finish and greater durability became available, the industry embraced these solvent-borne coatings in favor of water-borne alternatives. Additionally, the industry found it easier to formulate and apply high-pig-

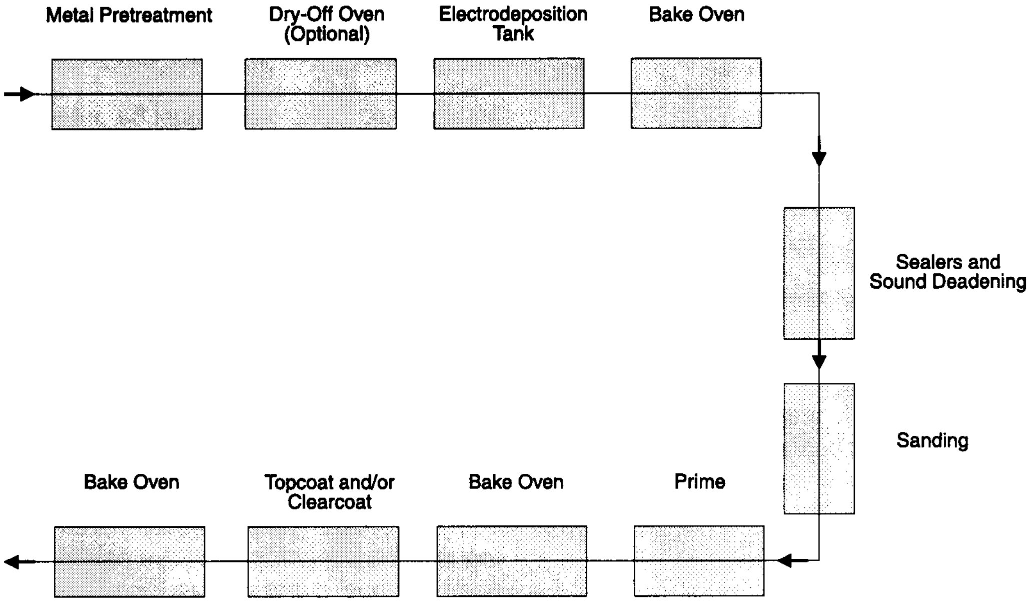

Figure **2-7. Schematic of a typical process for applying a primer-topcoat system In the automotive industry.**

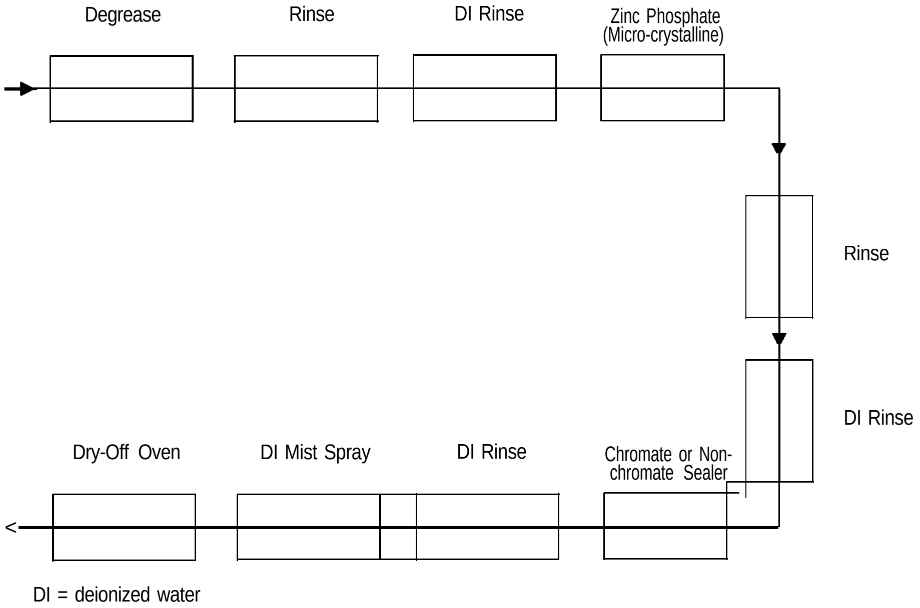

Figure 2-8. Schematic of a typical process for applying a zinc phosphate coating in the automotive industry.

ment-loaded basecoats, particularly those containing metallic pigments, in solvent-borne systems.

The industry returned to water-borne basecoats in the 1980s when improved formulations became available. Water-borne basecoats also are used extensively on automotive plastics.

2.3.2.2 Coating Systems

Primer-topcoat systems for the automotive industry can include any of the following components:

- *Primers:* Most primers are applied by electrodeposition and many are based on anodic or cathodic formulations, although cathodic epoxy is the most popular.

  New electrodeposited primers tend to be low in VOCs and heavy metals and they yield good coverage and corrosion resistance (2). Water-borne primer surfacers also are being tested by the industry.

- Basecoats: Both conventional solvent-borne basecoats and the newer water-borne systems are acrylic melamine formulations.

- Clearcoats: These finish coatings are available in many forms:
  - Conventional solvent-borne acrylic melamine.
  - New water-borne acrylic melamine.
  - Two-component polyurethane.

  - One-component polyurethane.
  - Scratch-resistant clearcoats based on silane chemistry.
  - Scratch-resistant clearcoats based on acid-epoxy chemistry.
  - Powder coatings.
- *Monocoats:* These coatings combine a basecoat and a clearcoat. Although most of them are solvent-borne, the industry is moving toward the water-borne basecoat/clearcoat systems.

These coatings are likely to gain greater popularity when baking temperatures can be reduced to the 250° to 285°F range. In particular, the industry is becoming increasingly interested in powder coatings (3).

2.3.2.3 Application Equipment

The automotive industry relies on sophisticated spray application systems to achieve superior coatings. Facilities (e.g., OEMs) typically operate down-draft, washwater systems that are totally enclosed to minimize dust generation and overspray. Most operations apply automotive coatings using both high-voltage, electrostatic turbo-bell systems and manual electrostatic or high volume, low pressure (HVLP) spray guns. Generally, airless or air-assisted airless spray guns are used on the finishing line exclusively for the application of sealers and sound-proofing coatings.

2.3.3 Abatement Equipment

Given the importance of paints and coatings application in the automotive industry, pollution control equipment is an important aspect of operations generally. Facilities typically use thermal oxidizers, catalytic incinerators, and carbon adsorbers, or a combination of these technologies, to control hazardous emissions. Moreover, the industry has pioneered the development of many low-emission coating systems. As a result of its prominence in the paints and coatings area, the automotive industry plays a leadership role in pollution prevention technologies, and many of the approaches detailed in this document are based on these innovations.

2.4 Operations for Plastic Parts

2.4.1 Surface Preparation

Paints and coatings are applied to plastic parts and components primarily for the automotive and electronics industries (e.g., business machines). The most notable difference between plastic and metal workpieces regarding paints and coatings operations is that surface preparation processes primarily rely on degreasing. Plastic workpieces are not subjected to phosphating, although in some operations pieces are scuff sanded to achieve a surface that will enhance coating adhesion.

Most plastic workpieces must be subjected to degreasing operations to remove contaminants, such as mold release agents. Because the characteristics of plastics can be quite varied, surface cleaning formulations must be carefully selected. For example, whereas some plastics are solvent sensitive, others are inert. Thus, when selecting a degreaser the facility operator must consider both the basic nature of the particular plastic material as well as the method by which it was manufactured.

Typically, high-volume production operations degrease plastic workpieces using a conveyorized spray washer process that includes rinsing with deionized water. Few operations clean plastic pieces with the vapor degreasing method. Regardless of the particular approach, the operator must guard against the tendency of some plastics to take on an electrostatic charge that can attract dust and undermine coatings.

Plastics hold some advantage over metal workpieces in terms of pollution prevention because phosphating is never part of the paints and coatings process. The more distinct advantage in this regard, however, is that because plastics do not corrode as metal does, less paint needs to be applied to the surface. Thus, the generation of pollutants is reduced.

2.4.2 Coatings Systems

The most widely used coating system for plastics is two-component polyurethane, which provides superior adhesion and exhibits outstanding durability. Moreover, this type of system can be formulated for application on both rigid and flexible plastics. In situations where the plastic in a workpiece is not compatible with polyurethane, epoxy formulations present an alternative that provides good adhesion and excellent performance characteristics.

Because most plastics are heat sensitive, coatings must be air- or force-dried at relatively low temperatures (i.e., below 180°F). Thus, coating systems that must be baked on at temperatures above 25O°F, such as acrylics, melamines, and polyesters, generally cannot be used on plastic workpieces.

2.4.3 Application Equipment

Coating systems are applied to plastic workpieces using both manual and automated spray gun systems. Facilities typically use conventional air-spray, air-assisted airless, and HVLP spray guns. Electrostatic guns are preferred when the plastic has been formulated to be moderately conductive or if a conductive primer has been applied.

Generally, requirements concerning the appearance of finished pieces cannot be met using airless spray guns. For similar reasons, dip or flow coatings are rarely used on plastic surfaces.

The type of spray booth used in plastic coating operations depends on the specifications for the finished workpieces.

2.4.4 Abatement Equipment

The use of emission abatement equipment for facilities applying paints and coatings to plastic workpieces varies widely. In general, large operations with high VOC-emission rates often are required to add control equipment, whereas smaller facilities with lower emission rates may be allowed to exhaust VOCs into the air without abatement.

2.5 Custom Coating Operations

Because custom coating operations work on a contract basis, the types of workpieces a particular facility processes can vary widely. For instance, a custom shop might shift coating operations from metal to plastic workpieces within a short period. In general, such operations are less sophisticated than the paints and coatings operations of OEMs and are capable of applying either liquid or powder coatings but not both. A very few custom houses (primarily in the Midwest) have the facilities for applying liquid, powder, and electrocoatings.

Typically, custom shops are required to use the coatings specified by the customer. In some locations, however, facility operators are encouraged by the stringency of environmental regulations (e.g., in California) to use water-borne materials when feasible.

Most custom shops apply paint exclusively with manually operated spray guns. If an operation handles large quantities of throughput for individual contract jobs, however, it is likely to have an automated process.

The general trend among custom shops is away from water-wash spray booths and toward dry-filter units, which are less expensive and easier to maintain. Additionally, with dry-filter spray booths, the operator does not need to use chemicals to detackify the coating overspray; thus, disposal of the paint waste sludge and contaminated water in the spray booth water trough are eliminated. A few of the larger shops are equipped with drive-in spray booths, with either cross- or down-draft capabilities. Most, however, operate with the cross-draft, walk-in type of booth, which can be three sided or totally enclosed.

In general, the volume of throughput at individual custom coating shops is sufficiently low that facility operators are not required to install emission abatement equipment. Exceptions are the few larger operations in this industry sector.

2.6 References

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27 Additional Reading

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Section 2
Pretreatment Factors

Chapter 3
Adhesion as a Critical Factor

3.1 Introduction

3.1.1 Pollution Prevention Considerations

Adhesion is a critical factor for ensuring the integrity of a coating. Only if a firm bond is established with a substrate can a coating provide the surface protection required by its product application. Many factors, however, can undermine the ability to thoroughly cover a surface. For metals and alloys, the principal threat to good adhesion is corrosion, which can result in degradation products, such as rust, that eventually push the coating away from the substrate. For plastics, the primary threat is from release agents, such as wax or silicone oil, that can remain on the surface after molding of the workpiece.

By anticipating these factors and then implementing process steps that guard against such threats to good adhesion, a facility operator can significantly extend the useful life of applied coatings. Typically, such measures result in process efficiency enhancements that save on operational inputs such as materials and labor. At the same time, because an efficient process is one that minimizes wastes, process enhancements usually will yield significant contributions to pollution prevention.

Right-first-time processing, a concept directly related to good adhesion, should be the overriding objective of the coatings operator seeking to reduce costs and minimize waste generation. Ensuring that all process steps in a paints and coatings operation are carried out thoroughly and consistently can yield considerable benefits in terms of avoided costs. As well as being labor intensive, corrective measures such as coating adjustments and reworks tend to require extensive use of solvents. A longer-term pollution prevention consideration concerning right-first-time processing is that when operations achieve good initial coating adhesion, a workpiece can be in service for a longer time before it requires refurbishing. The recoating of workpieces returned from service, such as truck bodies, requires extensive processing to achieve proper adhesion. Thus, by reducing the volume of recoating work, the paints and coatings industry can make considerable strides in terms of pollution prevention.

Good adhesion is presented in this chapter as a fundamental concept for all pretreatment and application steps in the paints and coatings process. Evaluating each process step in terms of how it promotes adhesion increases the likelihood that opportunities for operational efficiency and waste reduction can be identified.

Decision-making criteria relevant to adhesion are highlighted in subsequent chapters.

3.2 Corrosion of Metals and Alloys

Because even superior coatings are microscopically porous, metals and alloys are vulnerable to the ravages of corrosion despite good adhesion. Over time, atmospheric moisture and oxygen, which are extremely low in density in relation to paint molecules, can penetrate a coating. How quickly this migration occurs, however, depends on many factors, including the coating's thickness and its porosity, which varies with resin type. Once water and oxygen reach vulnerable sites on the substrate, the corrosion process can begin.

Nonetheless, corrosion, which is the principal cause of coating failures on metal substrates, can be controlled to a significant degree with conscientious surface preparation and coating application (1). These processes should be based on an understanding of the mechanisms of corrosion and how to prevent it.

3.2.1 Basics of the Corrosion Process

Corrosion is the electrochemical process by which the material integrity of a metal or alloy is gradually degraded. The process involves two physical mechanisms: a chemical reaction and the flow of electric current. Thus, when subjected to humidity and oxygen, steel will corrode as microscopic condensation forms and conducts electricity between reactive areas on the surface.

More specifically, condensation acts as an electrolytic solution in which soluble compounds such as salts, acids, or alkalis conduct electricity via the movement of ions. Rain, sea mist, and tap water all contain these soluble compounds. When subjected to an electrolyte, the more reactive areas of the steel's surface (the anodes) dissolve into the solution, generating electrons that flow through the steel to less-reactive areas (the cathodes). At these sites, oxygen and hydroxyl ions combine to form rust.

3.2.2 The Science Behind Corrosion

The process known as galvanic corrosion occurs when two metals that have different oxidation potentials are connected electrically and immersed in an electrolyte. Table 3-1 lists the most common metals and their respective oxidation potentials. Those higher up in the list are generally more reactive; elements with the lowest oxidation potential appear at the bottom of the list (i.e., platinum and gold, the “noble metals”).

If two dissimilar metals, such as copper and iron, were connected with a piece of wire and immersed in an aqueous electrolyte, the more reactive of the two metals would dissolve, in this case the iron (Figure 3-l). In such a galvanic couple, the metal that dissolves is called the anode. As this dissolves, it discharges an excess of electrons to the remaining solid metal, giving it a negative charge. The wired connection between the two electrodes allows oxygen and hydroxyl ions from the electrolyte to be drawn to the less reactive of the two metals, known as the cathode. Here they take on excess electrons and form new hydroxyl ions. Ions are atoms carrying either a positive or negative charge (e.g., when an atom of iron loses two electrons, the iron becomes a positively charged iron ion).

Table 3-l. Electromotive Force Series (2)

Electrode Reaction		Standard Oxidation Potential E^{o} (volts), 25°C
Lithium	$Li = Li^{+} + e$	3.05
Magnesium	$Mg = Mg^{+2} + 2e.$	2.37
Aluminum	$Al = Al^{+3} + 3e.$	1.66
Titanium	$Ti + Ti^{+2} + 2e.$	1.63
Manganese	$Mn = Mn^{+2} + 2e.$	1.18
Zinc	$Zn = Zn^{+2} + 2e.$	0.763
Chromium	$Cr = Cr^{+3} + 3e.$	0.74
Iron	$Fe = Fe^{+2} + 2e.$	0.440
Cadmium	$Cd = Cd^{+2} + 2e.$	0.403
Cobalt	$Co = Co^{+2} + 2e$	0.277
Nickel	$Ni = Ni^{+2} + 2e.$	0.250
Molybdenum	$Mo = Mo^{+3} + 3e.$	0.2
Tin	$Sn = Sn^{+2} + 2e.$	0.136
Lead	$Pb = Pb^{+2} + 2e.$	0.126
Hydrogen	$H_2 = 2H^{+} + 2e$	0.000
Copper	$Cu = Cu^{+2} + 2e$	-0.337
Silver	$Ag = Ag^{+} + e$	-0.800
Mercury	$Hg = Hg^{+2} + 2e.$	-0.854
Platinum	$Pt = Pt^{+2} + 2e.$	-1.2
Gold	$Au = Au^{+3} + 3e.$	-1.5

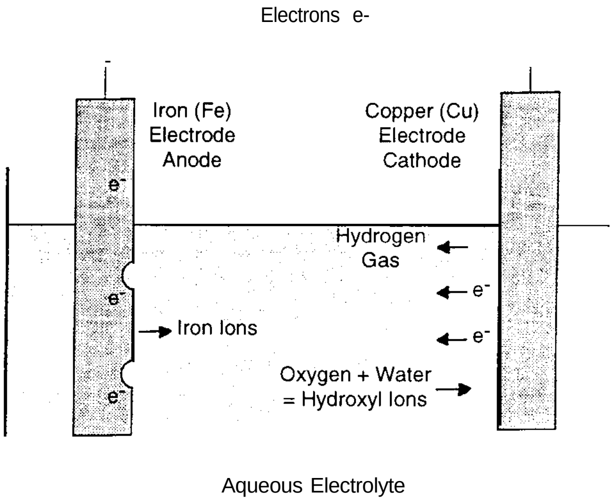

Figure 3-1. Movement of electrons and ions in corrosion process involving a galvanic couple.

The newly formed hydroxyl ions then move through the electrolyte toward the iron surface where the iron ions (Fe^{2+}) react with the hydroxyl ions (OH) to form iron oxide, or rust. This process is considered an electrochemical reaction because it cannot occur unless a chemical reaction takes place along with the flow of electric current.

To illustrate the science of corrosion, Figure 3-l portrays an electrical connection between anodes and cathodes on separate pieces of metal connected by a wire. In contrast, Figure 3-2 illustrates how corrosion occurs on a single piece of steel. Although steel is composed primarily of iron, depending on the type of alloy, steel also comprises small amounts of carbon, magnesium, copper, silicon, and other elements. On a single piece of steel, the base metal of the alloy conducts the electric current between the anodes and cathodes on the surface.

Once atmospheric moisture and oxygen come into contact with the steel surface, iron will dissolve at the an-

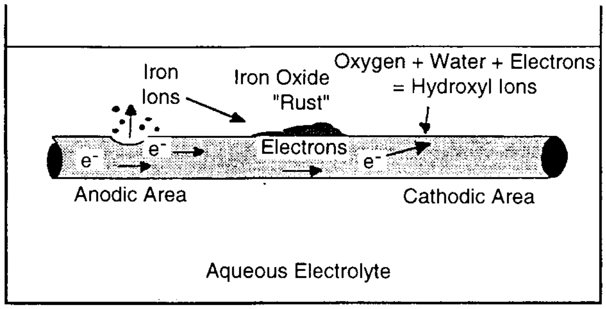

Figure 3-2. Mechanism of corrosion on a steel substrate (3).

odes to form iron ions. The electrons given up by the iron ions then will flow through the metal to the cathodes, where they are taken up by water and oxygen to form hydroxyl ions. Finally, a reaction between the positively charged iron ions and the negatively charged hydroxyl ions occurs, forming rust.

3.2.3 Fundamentals of Corrosion Prevention

It is known that when two metals with different oxidation potentials are connected and subjected to an electrolytic solution, corrosion of the more reactive metal is accelerated. For instance, if a piece of magnesium, which is relatively high in the electromotive force series (Table 3-1), and a piece of iron, which is lower in the series, are connected and immersed in a mild acid bath, the magnesium will corrode more rapidly than if it were immersed alone. The piece of magnesium would corrode at an even faster rate, however, if it were connected to a piece of copper, which has a lower reaction rate than iron. Thus, the greater the difference in oxidation potential between two pieces of metal, the faster the corrosion rate.

The relative rate of degradation for various metals is fundamental to the concept of sacrificial, or cathodic, protection against corrosion. This concept relates to the converse of accelerated corrosion, which is that the less reactive of two metals will degrade at a slower rate than if the two metals were not in contact. Based on this principle, iron will corrode more slowly when it is connected with lithium, which has the highest oxidation potential, than when coupled with magnesium.

Sacrificial protection is used extensively throughout the world to control the corrosion of metals and alloys. For instance, the steel beams in San Francisco's Golden Gate Bridge are regularly painted with a zinc-rich primer to protect the structure against the continua! assaults of fog and salt air. This galvanic coupling prevents corrosion of the iron while sacrificing the zinc, which has a far higher reaction rate.

Of the naturally occurring elements listed in Table 3-1, lithium is the most reactive, while gold has the lowest oxidation potential. Hydrogen, which is the only nonmetal in this selected list, has a reaction rate of zero and thus functions as a point of reference between elements with a positive or negative oxidation potential.

More generally, corrosion can be prevented by controlling any one of the following factors:

- Dissolution of the metal at the anode.
- Conduction of charged ions via the aqueous electrolyte.
- Conduction of electrons via the metal surfaces.
- Conjoining of chemical species formed at the anode and cathode.

3.3 Preventing Corrosion by Ensuring Proper Adhesion

The ultimate objective of a paints and coatings operation is for the finish on a workpiece to adhere so thoroughly that moisture and oxygen will be prevented from contacting the metal substrate and initiating the chemical reactions that lead to corrosion. Adhesion is critical because, even when a superior bond between the substrate and the finish is achieved, over time electrolytes will diffuse to the metal surface through micropores in the coating. Thus, the primary role of coatings for preventing the corrosion of metal is in restricting the movement of ions in the electrolyte from cathode to anode. Only through proper adhesion to the substrate can coatings present an effective impediment to this flow of electrons.

3.3.1 Mechanisms of Adhesion

The four mechanisms by which a primer coating can successfully adhere to a substrate are as follows (4):

- Primary bonding involving covalent or ionic interaction (e.g., chemical reactions). (Since most primers are formulated to have an excess of hydroxyl ions, adhesion is improved when the substrate has an excess of hydrogen ions. Thus, metal surfaces should be slightly acidic [i.e., a pH of 5 to 6].)
- Secondary bonding involving dipole-dipole interactions, induced dipole interactions, and dispersion forces (e.g., Van der Waal's forces).
- Chemisorption involving the formation by adsorption of chemical bonds between liquid molecules and a solid surface.
- Mechanical adhesion involving roughening of the substrate (e.g., abrasive blasting).

Although all four mechanisms can occur at the same time, each exhibits a different degree of effectiveness. In most cases, primary bonding, which relies on the composition of the primer to provide covalent or ionic interaction, is the most important of these mechanisms. When the substrate is especially smooth, such as a polished surface, mechanical adhesion is usually a critical mechanism.

3.3.2 The Importance of Proper Wetting

Superior wetting of the primer to the substrate is essential if good adhesion is to occur. For a liquid coating to spread over a solid surface, the critical surface tension of the solid must be greater than the surface tension of the liquid. Thus, as illustrated in Figure 3-3, a drop of

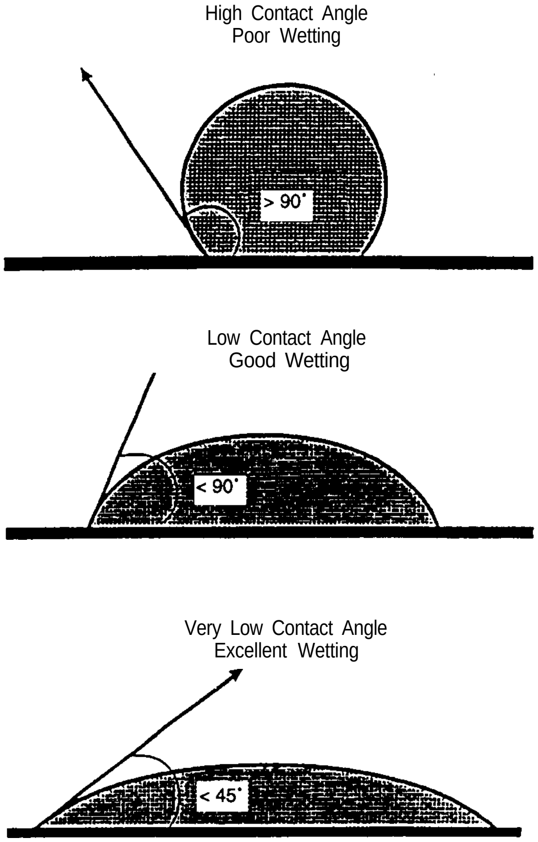

Figure 3-3. Coating contact angle relative lo wetting of surface.

liquid with a high contact angle relative to a substrate with a low surface tension will wet a smaller area than a drop with a low contact angle. While a drop of liquid with a contact angle even slightly below 90 degrees will provide relatively good wetting, a contact angle close to 45 degrees can make a considerable difference in surface coverage.

Depending on whether molecules are similar in character, the tension forces that hold them together are either cohesive or adhesive. Molecules of similar character (e.g., water molecules) are held together by cohesive forces, whereas unlike molecules (e.g., water and glass) are held together by adhesive forces. The relevance of this distinction in regard to surface tension can be illustrated using droplets of different liquids placed on a piece of glass. A drop of mercury will bead up rather than wet the glass because the cohesive forces within the mercury are stronger than the adhesive forces between the mercury and the glass surface. In contrast, a drop of water will spread out on the glass surface because the adhesive forces between the water and the glass are slightly stronger than the cohesive forces within the water droplet. Thus, between the two liquids, water demonstrates the better wetting properties on glass. If a surfactant such as soap were applied to the glass, the water would wet the surface even more thoroughly because the droplet's adhesive properties would be strengthened over its cohesive properties.

Surface tensions for water and mercury are 73 dyne/cm and 465 dyne/cm, respectively. In contrast, most of the common solvents, such as acetone, n-butyl alcohol, toluene, and xylene, have surface tensions in the range of 20 to 30 dyne/cm (Table 3-2). Steel has a surface tension in the range of 1,700 to 1,800 dyne/cm (Table 3-3). Solvents with surface tensions of 20 to 30 dyne/cm will wet a clean piece of steel more easily than water.

For powder coatings, surface tension becomes a critical factor when the applied powder melts and liquifies as it is heated in a high temperature oven (>250°F). If its wetting properties are good, the powder will easily flow over the substrate.

As indicated by Figure 3-4, at the microscopic level a typical substrate has considerable variation. Poor wetting (as shown in Figure 3-4a) leaves a gap, making it easier for corrosion to push the coating away from the substrate. When proper wetting is achieved (as shown in Figure 3-4b), the corrosion process is impeded.

3.3.3 The Role of Surface Contaminants

The inability to sufficiently wet a surface can be due to the presence of contaminants such as oil and grease on

Table 3-2. Approximate Surface Tension of Substances in Contact With Their Vapor (5)

	Surface Tension (dyne/cm)
Acetone	24
n-Butyl alcohol	20-26
Ethyl **acetate**	20-26
Glycol	48
Mercury	465
Methylene chloride	27
Toluene	27-29
Xylene	28-30
Water	**73**

Table 3-3. Approximate Surface Tension of Metallic Elements in Inert Gas (5)

	Surface Tension (dyne/cm)
Chromium	1,500-1,600
Iron	1,700-1,800
Manganese	1,100
Molybdenum	1,915-2,250
Nickel	1,700-1,800
Titanium	1,500-1,600
Zinc	750-800
Copper	1,200-1,300

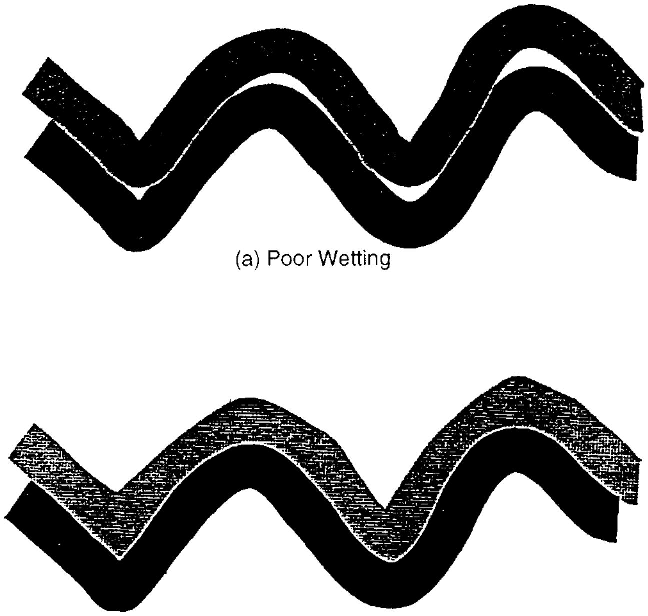

Figure 3-4. Cross-sectional view of surface wetting.

the substrate. Other contaminants such as scale and weld slag may initially accept a coating but cause it to fail prematurely. The thorough cleaning of workpieces before applying coatings can remove such contaminants and ensure long-term durability.

3.3.3.1 Oil and Grease

The presence of oil or grease on a substrate can prevent a coating from thoroughly wetting the surface, especially if the surface tension of the coating is slightly higher than that of the surface contaminants. For example, consider how water beads up on the surface of a greasy plate when held under a faucet. This occurs because water droplets have a surface tension of approximately 73 dyne/cm, while grease can have a tension in the 20 to 50 dyne/cm range. Washing the grease from the plate would raise the surface tension above that of the droplets, facilitating thorough wetting. Water flowing across the clean plate in sheets would indicate that the contact angle is extremely low (i.e., well below 90 degrees).

This example illustrates that the coating (e.g., the primer) will not adhere if it cannot make direct contact with the substrate. For instance, hydroxyl ions in a primer may not have an opportunity to react with a slightly acidic metal surface. Although some degree of mechanical adhesion may occur if the surface has been roughened, overall adhesion is likely to be poor.

Another important reason to remove oil and grease from a substrate concerns the integrity of the coating. Consider that primer coatings, for instance, are precisely formulated to provide specified performance properties. When a primer is applied over a film of oil or grease, solvents in the primer can dissolve the contaminants, incorporating them into the coating. The dissolved contaminant can in effect change the coating formulation and undermine its performance properties.

3.3.3.2 Scale (Oxides)

Scale is a flaky oxide film that forms on metal that has been heated to high temperatures. For instance, a type of scale known as iron oxide forms on steel when it is heated in the rolling process. Although iron oxide is inert to corrosion, its brittleness and tendency to form in multiple layers of varying physical characteristics can seriously compromise coating adhesion. Moreover, scale can act as a cathode to the adjacent metal anode; thus, as moisture penetrates the pores of the coating, corrosion occurs at the edge of the scale formation, where the galvanic couple is established. Moisture also can activate corrosive salts (e.g., ammonium salts, chlorides, and sulfates) that can be bound up in scale or generally in the atmosphere in industrial process settings. Eventually, the corrosion spreads under the scale and lifts it from the substrate (Figure 3-5).

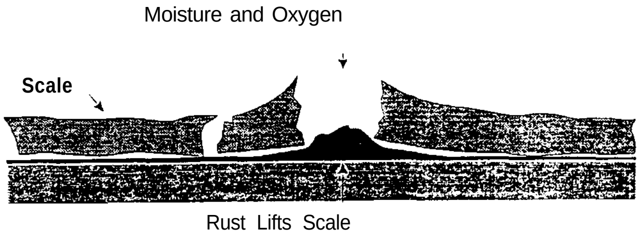

Figure 3-5. Cross-sectional view of surface spalling caused by scale.

Depending on the end-use of the workpiece, many companies apply finishes directly over scale. When such coatings are exposed to the elements, particularly in humid or marine environments, they tend to degrade rapidly. The result of such adhesion failures is that the coating flakes, or spalls. For example, consider how rapidly paint applied to steel handrails and stanchions tends to fail when constantly exposed to ocean winds. When applied directly over corrosion, the coating is likely to fail within a few months and require repainting. Proper surface preparation could extend the life of such coatings considerably.

In contrast to iron oxide, oxide on aluminum forms a thin, transparent film on the substrate when it is exposed to oxygen at ambient temperatures. As with other surface contaminants, this film should be removed from the substrate before a coating system is applied.

3.3.3.3 Welding By-Products

Adhesion also can be undermined by weld slag and spatters in the area of a welded seam. Because the seam itself is highly prone to corrosion and is often where coating failure begins, thorough preparation of such areas is particularly important. Like scale, weld slag can include corrosive substances that undermine surface adhesion when activated by moisture. In contrast, spatters encourage premature corrosion by their irregular profiles, often with sharp peaks, which make them difficult to cover and likely to protrude from the coating (Figure 3-6). Another concern is that the area around a weld seam can be slightly alkaline. This can cause a compatibility problem with the primer, which should be applied to metal substrates that are slightly acidic (i.e., a pH of 5 to 6).

The most effective approach for preparing a welded surface before painting calls for removing all spatters and slag material, either through grinding or abrasive blasting. The weld seams should then be thoroughly wiped down using a cloth moistened with a low concentration phosphoric acid to adjust the pH.

Additional preventive measures include brushing the weld seam with a corrosion-resistant primer before spraying the entire piece with the primer coat. This additional step ensures that the primer covers most if not all surface irregularities. One company using this labor-intensive approach reports that an earlier problem with paint failures around weld seams has been essentially eliminated.

3.4 Adhesion Considerations Specific to Plastic Substrates

Plastics are complex organic composites that present a particular challenge to paints and coatings operations. For example, most plastics have a surface tension in the same range as organic coatings, making adhesion generally problematic (Table 3-4). To some degree, this challenge can be addressed with the use of coatings specifically formulated for a lower surface tension. Because the range for adjustment is quite narrow, however, ensuring that the substrate is free of contaminants is even more important for coating plastics than for metals. Of particular concern are release agents (e.g., wax or silicone oil), which are used during molding operations to keep the surface of the workpiece from adhering to the form. Additionally, plasticizers which are added to the plastics blend to enhance flexibility, can contaminate the substrate. In some cases, plasticizers migrate to the surface over time to undermine a workpiece's long-term durability.

For most plastic workpieces, thorough cleaning of the surface ensures that coating adhesion meets end-use specifications. Certain plastics, however, such as polypropylene, are so inert that additional pretreatment may be required. Recommended approaches include light abrasion of the surface or heating the workpiece to alter the chemical characteristics of the substrate (e.g., using hot flame or gas plasma technology).

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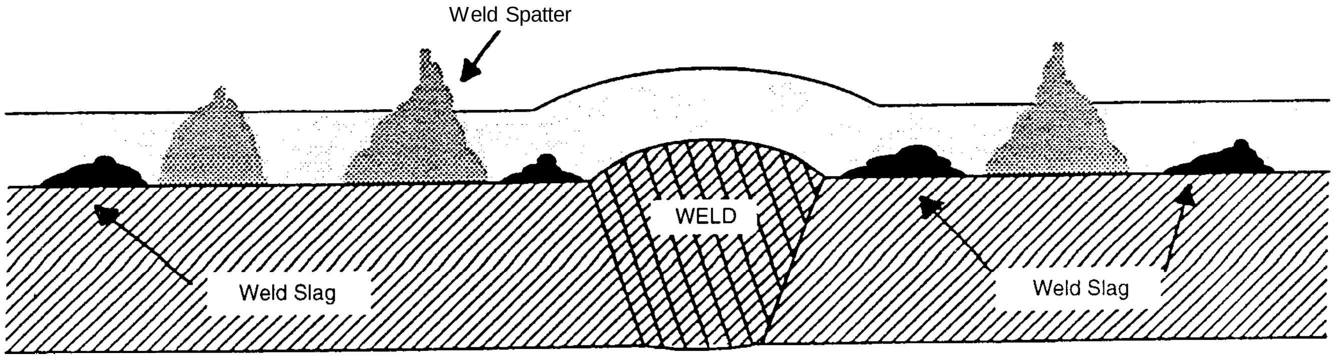

Figure 3-6. Cross-sectional view of compromising effect of weld slag and spatters on a coating.

Table 3-4. Surface Tensions of Coating Ingredients Versus Plastic Substrates (6)

Solvents	dyne/cm	Resins	dyne/cm	Substrates	dyne/cm
				Plastics:	
Water	72	Acrylic latec	30-38	PVC (nonplasticized)	**34-44**
Butyl cellosolve	28	Acrylic resin solution	32-38	PVC (plasticized)	25-35
Isopropyl alcohol	22	Polyurethane emulsion	32-36	PP	28-30
Propylene glycol methyl ether (PM)	28	Polyurethane resin solution	28-34	Polyester SMC, BMC	22-30
Dipropylene glycol methyl ether (DPM)	31	PV Ac latec	30-35	PTFE	19-20
N-methyl-pyrrolidon (NMP)	30	Melanine resin	42-58	ABS	30-38
		Polyester resin solution	34-38		
				Coatings:	
				Waterborne primers	29-40
				Waterborne topcoats	27-38

PVC = polyvinyl chloride
PP = polypropylene
SMC = sheet molding compound
BMC = blow molding compound
PV Ac = polyvinyl acetate
PTFE = polytetrafluoroethylene
ABS = acrylonitril-butadiene-styrene

Chapter 4
Considerations Regarding Vendor-Supplied Materials

4.1 Introduction

4.1.1 Pollution Prevention Considerations

Often, the earliest opportunity for the manager of a paints and coatings operation to avoid extensive pretreatment of workpieces-and thus prevent the generation of excess wastewater, residual pollutants, toxic emissions, or other wastes-is when taking delivery of vendor-supplied materials. To the degree possible, operators should stipulate to vendors that delivered materials must be free of corrosion and contaminants. It is then contingent upon the operator to maintain the supplied materials in the same “coating-ready” condition in which they arrived.

Delivered materials should be stored indoors whenever possible to protect them from the elements. When floor space is not available for holding inventory, materials should be thoroughly covered for outside storage and kept above ground level. More streamlined operations, however, minimize the likelihood that materials will corrode during storage by relying on a just-in-time delivery system. Such systems have been used in most industry sectors to control inventory costs. In the paints and coatings sector, they can afford additional benefits associated with pollution prevention.

The potential for vendor-supplied materials to undermine the long-term durability of a finished workpiece is easily overlooked. Corrosion on raw materials or on a component or part, however, can significantly shorten the service life of an otherwise high-quality product. This chapter considers various options for working with suppliers to reduce this likelihood.

4.1.2 Decision-Making Criteria

Decision-making criteria relevant to vendor-supplied materials, as addressed in this chapter, are highlighted in Table 4-l.

Table 4-1. Decision-Making Criteria Regarding Vendor-Supplied Materials

Issue	Considerations
Are raw materials and components supplied by the vendor with an application of rolling oils and/or corrosion preventive coatings?	• Such coatings can be effective in preventing corrosion; however, they can be difficult to remove prior to fabrication or priming. • Consideration should be given to requiring the vendor to use oils and preventative coatings that can be easily removed using an aqueous degreaser or detergent cleaner. • Consideration should be given to purchasing raw materials and components without a coating of oil or a corrosion preventative, thus minimizing the generation of wastewater and emissions associated with cleaning operations.
Can pretreated materials be substituted for standard materials?	• If so, a cost-benefit analysis of this approach should be conducted. • This approach can minimize the generation of wastewater and emissions associated with cleaning operations.
Are some raw materials and components stored outdoors?	• If so, materials should be stored under cover, even if this means covering them with a tarpaulin. • Additionally, consideration should be given to treating materials with a rust converter before application of a primer-topcoat system. • Consideration should be given to implementing a program for just-in-time (JIT) delivery of materials to minimize corrosion of materials on site.

4.2 Raw Materials

4.2.1 Protective Coatings and Treatments

For most operations that both fabricate products and apply paints and coatings, steel represents the largest portion of vendor-supplied raw materials. Aluminum is also widely used in fabrication because it is lightweight and less susceptible to corrosion. Depending on how it will be used in the manufacture of a workpiece, the raw material may be delivered in the form of plates, sheets, or extrusions. Milling operations typically involve application of one of the following types of coatings:

Rolling oils, which are lubricants used to minimize friction between the metal and the pressing machinery; also, these oils provide some corrosion protection, primarily during transportation and short-term storage.

Corrosion preventatives, which are organic formulations used specifically to protect the substrate in the longer term (e.g., by displacing condensed moisture).

Although important for minimizing the corrosion of metal between milling and the application of a finish coating, protective coatings can be difficult to remove, especially if they have been on the substrate for an extended period. Whereas some of the coating may be removed incidentally during fabrication, manufactured workpieces are likely to require extensive washing or abrasive blasting before surfaces are sufficiently clean to receive paint. Thorough washing can consume large volumes of water, and many of the degreasers in use are solvent based, raising process management issues involving toxic emissions and contaminated wastewater (see Chapter 5). Some situations may require the use of several solvents to remove protective coatings, further complicating the overall process. Abrasive blasting can raise other pollution prevention considerations, such as dust generation (see Chapter 8).

To minimize process demands and wastewater outflows, the facility operator should specify that vendors only use protective coatings that can be readily removed by washing with one of the following:

- Ambient water and an aqueous degreaser
- Hot water and a detergent solution
- Steam or high-pressure water

Alternatively, the facility operator could purchase specially treated raw materials that would not require application of a corrosion preventative before delivery. Galvanized steel, for instance, receives a deposition coating of zinc during the milling process to provide corrosion resistance. Similarly, stainless steel includes other elements (e.g., chromium, nickel, molybdenum) that make the alloy nearly immune to ordinary rusting. While these alternatives can be more expensive, the cost should be weighed against savings in terms of avoided process steps and reduced waste generation.

Another alternative is for the fabricator to use raw materials that have been precoated by the vendor. Coil coating, powder coating, and electrodeposition operations all generally yield a vendor-applied finish that is sufficiently resilient for the fabricator to post-form workpieces from the stock material. For instance, often sheet steel or aluminum undergoes coil coating operations in which the surface is thoroughly cleaned before a white or neutral-tone finish is applied. This material can be cut and punched in forming operations with little or no damage to the surface. Usually there is no need for the fabricator to apply a topcoat to the workpiece after forming operations.

4.2.2 Storage

Vendor-supplied raw materials should be carefully stored so that they will not be subjected to moisture and contamination. This is especially important for metal that has received neither a protective coating or undergone some type of pretreatment. Because steel is particularly vulnerable to corrosion, it should be stored indoors when possible. When outside storage is the only option, materials should be well covered and raised above the ground. Protection from the elements is of particular concern in humid or marine environments.

If steel begins to corrode while in storage, the operator may be able to arrest the process with a rust converter, a chemical formulation that converts iron oxide to inert matter. Depending on the durability requirements of the workpiece, a primer can be applied directly over the treated substrate, which with most converter formulations turns black within minutes. For long-term durability, the chemicals and oxides should be cleaned from the steel before a coating system is applied, either through surface degreasing or abrasive blasting.

4.3 Components and Parts

4.3.1 Protective Coatings and Primers

Operations that apply paints and coatings to workpieces assembled on site using vendor-supplied components and parts should be attentive to the condition of delivered materials. Often, an establishment will go to great lengths to ensure that the surfaces of its fabricated pieces are thoroughly prepared for finish coating while overlooking the substrate quality of supplied components. A component or part that corrodes prematurely, however, can undermine the overall quality of an assembled product.

To avoid problems with supplied components and parts, the operator should require that the vendor supply materials with a protective coating that is consistent with the primer-finish coating system that will be applied. The operator may want to specify the use of compositions that can be removed using a nonsolvent degreaser or detergent.

For some materials, a primer coat will need to be applied by the vendor. When the vendor is supplying assembled components that include sophisticated electronics or computer circuits, for instance, the operator should be directly involved in the selection of the undercoating. Such sensitive and expensive components cannot be readily cleaned and reprimed after delivery if the undercoating is found to be incompatible with the finish coating. Moreover, whenever components and parts must be cleaned and reprimed, the operator incurs added costs and generates unnecessary wastes. Operators should always specify the use of corrosion-resistant primers that are in keeping with workpiece quality specifications. Additionally, operators should require the use of pretreated (e.g., galvanized steel) or finish coated (e.g., electrocoated) materials when appropriate.

4.3.2 Storage

Storing components and parts to protect them from moisture and contaminants often is even more important than it is for raw materials. The substrate of a sophisticated assembly that begins to corrode while in storage may be impossible to thoroughly clean. Similarly, parts may have intricate geometries that hide contaminants or the beginnings of corrosion from view. For these reasons, along with their generally high value, components and parts should be stored indoors whenever possible. When stored outdoors, they should be completely wrapped for protection and inspected routinely.

4.4 Just-in-Time Delivery

Just-in-time delivery of supplies is practiced by many companies to control costs through the careful management of inventory. For paints and coatings operations, however, this technique can also present opportunities for avoiding the cost of additional pretreatment for materials that have begun to corrode while stored on site. The degradation of vendor-supplied materials is a particular concern for establishments that increasingly dedicate available floor space to operations in an effort to remain competitive, while resorting to yard storage of inventory.

At the least, implementing such a program will free up floor space and minimize the contamination of raw materials and components. In the best case, close control of inventory might eliminate the need to receive vendor-supplied materials with a corrosion-prevention coating that ultimately must be cleaned from the substrate.

To implement a successful just-in-time inventory program, the operator must work in close coordination with suppliers. Generally, this requires establishing computer links that enable the operator and principal suppliers to share inventory data so that they can work together in the tracking and in-time delivery of materials. This link is often established using a computer networking system called electronic data interchange, or EDI. In a highly sophisticated undertaking, computers also can be used to model material consumption patterns, providing additional data for refining inventory needs. In some industry sectors, cooperative efforts between producers and suppliers have evolved into strategic “partnerships” in the management of inventory, significantly reducing the amount of time materials remain on site before they are needed (1).

Even without computer links, operators should be in regular contact with their principal suppliers in an effort to minimize the need to manage excess inventory that is prone to corrosion. Frequent communication with suppliers will reduce the potential for misunderstandings about the need for coating-ready materials. Moreover, regular contact will afford an opportunity for the operator to implement and oversee a policy according to which materials would only be accepted if delivered in their agreed-upon condition.

4.5 References

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Chapter 5
Surface Degreasing: Alternatives to Conventional Solvent-Based Methods

5.1 Introduction

5.1.1 Pollution Prevention Considerations

Thorough degreasing of a workpiece is an essential pretreatment step in the paints and coatings process for ensuring proper adhesion. Even exemplary application processes and superior coatings cannot provide a reasonable measure of durability if the various oils and greases, corrosion products, waxy films, and tars that can become attached to a substrate are not first cleared away.

Unfortunately, many of the chemical agents that are the most effective for removing such contaminants from a workpiece raise significant concerns about pollution. Indeed, solvents in several conventional degreasers are strictly regulated at the federal level and are scheduled to be phased out of use early in the next decade under an international agreement. Facility operators that choose to use degreasers based on these particular solvents in the interim will incur the additional costs associated with controlling hazardous air emissions. In some cases, the cost of the solvents themselves is being driven up by taxes that create an incentive for facility operators to seek out less-toxic alternatives. Because solvent-based degreasers are generally easy to recycle, however, operators will have opportunities to maximize the use of currently available stocks.

At present, aqueous degreasers represent the best alternative to solvent-based formulations in regard to pollution preventions considerations. These water-based solutions are already widely used in the industry to remove an array of surface contaminants-from corrosion to waxy films. Because they are less volatile and do not pollute the atmosphere, aqueous degreasers are generally less expensive to use. Nonetheless, certain aqueous cleaning approaches can generate considerable volumes of wastewater that must be treated before being released to a publicly owned treatment works. Moreover, the use of aqueous formulations necessitates the addition of a rinse step to the degreasing stage.

For surface contaminants that are particularly difficult to remove, such as heavier grease and tar, semi-aqueous degreasers present an alternative that lies between solvents and aqueous formulations. Whereas the organic compounds in semi-aqueous degreasers are effective cleaning agents, they are also considered hazardous air pollutants (HAPs). Because semi-aqueous degreasers are less toxic than solvents, however, they are easier and less expensive to use.

A potential third alternative is still in development. Researchers are working on hydrofluorocarbons (HFCs) that promise effectiveness in removing stubborn surface contaminants and pose little or no threat to air quality. Current indications are that the first of these may become available by the end of the decade.

These pollution prevention considerations are presented in this chapter in the context of the various approaches currently used to degrease workpieces. Conventional solvent methods are discussed first, followed by aqueous alternatives.

5.1.2 Decision-Making Criteria

Decision-making criteria relevant to surface degreasing process efficiency and alternatives to conventional solvent-based methods, as addressed in this chapter, are highlighted in Table 5-1.

5.2 Basic Practices and Regulatory Considerations

5.2.1 Typical Oils and Grime on Substrates

The operator of a paints and coatings facility should determine the best approach for cleaning workpieces based on an assessment of the particular types of contaminants on the substrate. Typically, contaminants fall into one or more of the following categories:

- *Oil and grime with a relatively low viscosity such that it easily flows at ambient temperatures.* These contaminants may contain chlorinated paraffins or sulphurized oils. Generally, such material can be removed with either a solvent-based or an aqueous degreaser.
- *Grime with a relatively high viscosity such that it does not flow.* These contaminants may include waxes, oxidized resins, and pastes or other soft and filmy matter. Generally, such material can only be removed

Table 5-l. Decision-Making Criteria Regarding Surface Degreasing Process Efficiency and Alternatives to Conventional Solvent-Based Methods

Issue	Considerations
Are the workpieces that need to be cleaned large (e.g., assembled machinery)?	• If yes, then the most effective method would be to use high-pressure, super heated steam or high-pressure hot water.
Have the workpieces already received a primer coating and will the cleaning be conducted to prepare surfaces for topcoat application?	• If yes, then cleaning with high-pressure hot water is recommended. • Only a low concentration of detergent may be necessary (consult degreasing formulation vendor). • A final rinse with hot tap water should follow the cleaning.
Are workpieces uncoated and will the cleaning be conducted to prepare surfaces for a primer-topcoat system?	• If yes, then the most effective method would be to use high-pressure, super heated steam or high-pressure hot water. • Only a low concentration of detergent may be necessary. • A hot tap-water rinse with a small concentration of phosphoric acid should follow the cleaning; this will give the substrate a slight etch and lower its pH (making it more acidic), resulting in enhanced coating adhesion.
Are the workpieces that need to be cleaned small enough for vapor degreasing, cold cleaning, or conveyorized spray washing or for immersion in a tank?	• If yes, then the use of high-pressure steam or high-pressure hot water might not be the most effective cleaning method.
Are workpieces already being cleaned in a vapor degreaser using 1,1,1 trichloroethane or CFC-113?	• If yes, consider substituting such solvents with an aqueous degreasing system. • Otherwise, consider near-term strategies such as substituting with methylene chloride, perchloroethylene, or trichloroethylene. • Other possible temporary substitutes to consider would include alternative HCFCs. • Factors to consider when selecting an alternative degreaser include: the nature of the grime on workpieces, the thoroughness of cleaning required for the particular end-product's application, and workpiece drying considerations.
Is the use of a solvent-based degreaser necessary, although some degree of residue can be tolerated?	• If yes, consider using a solvent that has a high boiling point and low vapor pressure to prevent unnecessary toxic air emissions. • Regardless, avoid the use of listed hazardous air pollutants and ozone-depleting compounds. • Experiment with alternative solvents to achieve the required substrate cleanliness (e.g., some cold cleaning approaches, in which the workpiece is immersed in a bath, can leave a residue). • Give strong consideration to the use of a semi-aqueous formulation (i.e., an emulsion comprising solvents and water). • Use of a semi-aqueous formulation in a degreasing process should include multiple rinses, using deionized water for the final rinse; additionally, workpieces should be dried with forced air.
Can pretreatment specifications be met with the use of an aqueous degreaser?	• If yes, consider using these less-toxic formulations, many of which have been proven effective through widespread use by the industry. • Aqueous degreasing processes should be given particularly close consideration for new facilities.
Are the workpieces that need to be cleaned too heavy to be cleaned in a conveyorized spray process?	• If yes, consider a system of one or more immersion tanks. • For enhanced, cost-effective cleaning, consider a system in which the workpiece is immersed first in a bath of aqueous degreaser (i.e., water, detergent, surfactants, and other chemicals) followed by at least a tap-water rinse.
Do the workpieces that need to be cleaned have complex geometries (e.g., channels, box sections, crevices), making spray washing an ineffective approach?	• If yes, same as above.
For the workpieces that need to be cleaned, is the production rate sufficiently low that continuous degreasing operations would not be cost effective?	• If yes, same as above. • As a rule of thumb, a degreasing operation that cleans less than 2 feet of production per minute is considered too slow to be cost-effective as a continuous operation.

Table 5-l. Decision-Making Criteria Regarding Surface Degreasing Process Efficiency and Alternatives to Conventional Solvent-Based Methods (continued)

Issue	Considerations
For the workpieces that need to be cleaned, is the production rate high enough to justify using a continuous system?	• If yes, consider a conveyorized spray process. • For enhanced, cost-effective cleaning, consider a system in which the workpiece is sprayed with an aqueous degreaser (i.e., water, detergent, surfactants, and other chemicals) followed by at least a tap-water rinse.
Regardless of the degreasing approach used, must the cleaned workpieces be dried rapidly to avoid the onset of flash rusting?	• If yes, it is likely that a high-temperature oven (at 230° to 400°F) will need to be included in the process line.

at higher temperatures or by using stronger solvents or higher-concentration aqueous degreasers.

- *Grime that may contain abrasives, carbonized films, buffing compounds, welding smut, metal or plastic chips and fines, dust, and even rust and scale* (i.e., oxides formed during hot working of the metal). Generally, such material can only be removed using particularly strong inorganic acids or specialty chemicals.

5.2.2 Basic Cleaning Approaches

Workpieces can be cleaned using any combination of the following basic approaches (1):

- Cleaning by mechanical or physical means, such as machining, abrading, pressure spraying, brushing, or wiping.
- Dissolving/washing by application of a chemical solvent.
- Washing/dissolving by application of an aqueous solution.
- Displacing/washing by application of a detergent (i.e., applying surface-active materials that displace the grime).

For general purpose workpieces, most cleaning operations involve either immersion of the piece in a tank of degreasing solution (batch operations) or spraying the piece with solution at low pressure (continuous, or conveyorized, operations). Immersion is generally recommended for smaller workpieces (i.e., component parts without electrical wiring), especially those with complex geometries (1). Whether to agitate the immersion solution can depend partially on the type of degreaser used (see Section 5.3.2 on Degreasing with Liquid Solvent). Spraying may be required for large workpieces, such as truck bodies, or when the additional contaminant removal afforded by impingement is an advantage.

5.2.3 Selecting a Cleaning Approach

A facility operator should follow the recommended steps outlined below when selecting an approach for cleaning particular types of workpieces (2):

1. *Determine the level of part cleanliness required.* Such an assessment must be based on the process-flow design of the particular operation (e.g., will a high level of cleanliness extend the useful life of subsequent baths?) as well as the quality requirements of the finished workpiece (e.g., do specifications call for a coating with long-term durability in extreme use conditions?).

2. *Research and make preliminary selections of the most appropriate degreasers and associated equipment for achieving the required level of cleaning.* This involves reviewing vendor literature and considering the cost and waste-generation implications of various options.

3. *Test run selected degreasers and associated equipment to confirm satisfactory performance under all anticipated operating conditions.* Operators should test similar degreasers from more than one vendor because a slight variation in formulation can result in a higher level of effectiveness. Even generic degreasers can vary in their formulations.

4. *Negotiate price with vendors of degreaser and associated equipment.* It pays to shop around, particularly when the operator has tested similar products that yield nearly the same results. In negotiating, the operator may want to establish that the vendor will provide training and support in use of the product and any associated equipment.

5. *Make final selections and apply for any operational and waste-related permits required by federal, state, or local authorities.* The operator may need to establish or modify recordkeeping procedures based on permit requirements (e.g., for reporting on emissions, water discharges, and waste disposal).

6. *implement the cleaning approach.* The operator should allow sufficient startup time for training employees and to refine the process. Quality control procedures should be developed and distributed.

5.2.4 *Regulatory Overview*

When assessing the appropriateness of various degreasers for a particular process, the facility operator should investigate the applicability of federal, state, or local regulations concerning the use of specific cleaning agents. The costs associated with some requirements can make the use of some solvent-based degreasers prohibitive, particularly for smaller operations. Most conventional solvent-based degreasers used in paints and coatings operations come under the following regulations:

- *Title III of the Clean Air Act Amendments of 1990:* This federal regulation establishes limits on the emission of HAPs, including those from certain degreasing solvents. Operations whose solvent emissions exceed these limits may be required to perform risk analyses and to install Maximum Achievable Control Technology (MACT).
- *Occupational Safety and Health Administration (OSHA) regulations:* These federal regulations establish limits on emissions of HAPs from materials considered particularly hazardous, including those from certain degreasing solvents.
- *The Montreal Protocol:* This international agreement and subsequent related federal regulations require that certain ozone-depleting compounds (ODCs) be phased out within the next several years. Under this agreement, the use of chlorofluorocarbon 113 (CFC-113) and 1,1,1 trichloroethane (methyl chloroform), the two most commonly used compounds in vapor degreasing operations, will be banned by 2000 and 2002, respectively. In the United States, the manufacture of both compounds will cease after 1995, leaving several years for inventories to be exhausted. Also under this agreement, fluorinated hydrocarbons (HCFCs), some of which also are included in solvent-based formulations, are expected to be phased out between 2020 and 2040.
- *State permit rules:* Under the Clean Air Act Amendments (i.e., the Title V Permit Rule), states are required to monitor "major" source categories of various pollutants, including compounds found in many degreasing solvents. Thus, facility operators must apply for a state permit before using solvent degreasers that include regulated compounds. Applications for Title V permits are required as of 1995; state compliance officials notify facility operators directly about the deadline for submitting an application. State officials may determine that an operation comes within the "minor" source category based on an assessment of the concentrations of listed compounds the applicant expects to use and the effectiveness of emission control equipment. The advantage of being designated a minor source is that applicable requirements are less stringent.
- *State implementation Plans (SIPs):* These programs monitor emissions of volatile organic compounds (VOCs), including those from solvent degreasers and solvent cleaning operations. Facility operators are advised to become familiar with VOC regulations in the state in which their facility is located.

More detailed information on regulatory considerations specific to the paints and coatings industry is available in the literature (3-5).

5.3 Solvent-Based Methods

Solvent-based methods for degreasing and cleaning[1] workpieces have been widely used throughout the industry for many years because they are particularly effective for removing surface contaminants from metals and high-performance plastics. Moreover, because they clean thoroughly and then evaporate in the ambient air without leaving surfactant residues on the substrate, no rinsing steps or oven drying is required. Another advantage is that, given the effectiveness of solvents in both their vapor and liquid forms, facility operators can use this method for many different types of cleaning applications. For example, vapor degreasing is widely used in the aerospace and electronics industries for cleaning entire pieces with complex geometries. In contrast, wipe cleaning with liquid solvents at ambient temperature (cold cleaning) enables line operators to degrease specific sections of workpieces that integrate sophisticated electronics.

Solvent use, however, generates emissions that are considered hazardous to the atmosphere and pose a threat to human health. As a result, the paints and coatings industry is investigating alternative degreasing and cleaning methods as well as ways to use solvents more efficiently while controlling emissions. This section discusses the advantages and disadvantages of solvent-based degreasing and cleaning methods along with recommended practices.

5.3.1 Vapor-Solvent Degreasing

5.3.1.1 Introduction

Over the years, vapor degreasing has been widely used in paints and coatings operations to clean the surface of various metals, ceramics, high-performance plastics, and electric and electronic components (e.g., printed

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[1] In this document generally, "degreasing" refers to the various liquid/vapor methods used in paints and coatings operations to clean substrates. The author recognizes, however, that some facility operators use the term degreasing to refer specifically to vapor degreasing. Thus, this particular chapter discusses vapor-solvent degreasing and cold-solvent cleaning as distinct pretreatment methods.

circuit boards). The process involves subjecting workpieces to the vapor form of a chlorinated solvent, typically 1,1,1 trichloroethane, CFC-113, trichloroethylene, or perchloroethylene (perc).

Vapor degreasers are highly effective in removing substrate contaminants without leaving a film of residue, making them particularly well suited to the demanding requirements of the electronics and aerospace industries. Additionally, capital and operating costs are low because this fairly simple, one-step cleaning approach requires only minimal floor space and limited line operator training; moreover, the process can be readily automated. Another advantage is that, given the vapor's rapid evaporation rate, workpieces can be air dried, thereby avoiding the cost of a drying oven.

The principal limitation of this approach is that emissions from solvents in conventional vapor degreasers can be damaging to the environment. Moreover, some evidence indicates that long-term exposure to certain concentrations of these compounds can pose human health risks, a particular concern for line operators. Because CFC-113 and 1 ,l ,l trichloroethane are considered ODCs, the United States and numerous other countries have agreed to phase out their use within the next 10 years under the Montreal Protocol and the Clean Air Act.

Other solvents used in vapor degreasing are being considered for further regulation at various levels of government. Perc, for example, is a listed toxic air pollutant under the Clean Air Act and is covered in a proposed National Emissions Standard for Hazardous Air Pollutants (NESHAP) (also known as the MACT Standard for Halogenated Solvent Cleaning Operations, 40 Code of Federal Regulations Part 63, Subpart T). Thus, despite the advantages associated with conventional vapor degreasers, alternative formulations are likely to be more cost effective over the long term for most operations.

5.3.1.2 Process Basics and Best Management Practices

In vapor degreasing, workpieces are suspended at ambient temperature in the headspace of a tank of heated degreaser solution, where they are subjected to chlorinated solvent in a vapor form. As the solvent vapor comes in contact with the cool surface of the workpieces, it condenses into a liquid, dissolving contaminants and carrying them off into the degreaser tank as drainage. There the heavier contaminants gradually sink to the bottom. Because vapor degreasing works on the basis of condensation, the cleaning action slows as the temperature of the substrate rises. Typically, workpieces are suspended in the degreaser tank headspace until the substrate temperature rises to that of the vapor, at which point condensation stops.

For the most part, the vapor degreasing tank is a ctosed-loop system in which vapor that does not condense on the workpiece collects on chiller coils that run up the walls of the tank. Figure 5-1 illustrates a typical vapor degreasing process. In such a system, condensate that forms on the chiller coils runs off into a separator, which removes water and allows solvent to drain back into the tank. Contaminants captured by filters during recycling are disposed of as sludge. The small amounts of vapor that do escape from the degreasing operation are either recycled or, if permitted, exhausted to the atmosphere. Inadequately recycled or exhausted vapors can pose a hazard to line operators.

Best management practices for enhancing process efficiency in the degreasing operation include the following (2, 7):

- For thorough cleaning, workpieces should be kept in the vapor zone until condensation has ceased.
- To control drag-out, workpieces should be removed slowly, allowing vapors to be drawn off into the exhaust system (i.e., a minimum of about 15 seconds or until parts are visibly dry). Workpieces that have porous substrates, which tend to entrap solvents, should be degreased by an aqueous or semi-aqueous method.
- To minimize emissions and ensure efficient solvent use, degreasing operations should be conducted in an enclosed area and the temperature of the degreaser solution should be monitored to control the rate at which vapors rise to the workpiece. Also, to minimize turbulence in vapor zone, workpieces should be moved in and out slowly.
- To control fugitive emissions and enhance recycling, vapor tanks should have a minimum freeboard ratio (i.e., depth to vapor zone relative to width of the tanks opening) of 0.75, although a ratio of 1.0 or greater is preferable. This step can be enhanced further with the addition of refrigeration. With a higher freeboard, vapors can be more effectively captured by chiller coils for recycling.

Other suggested practices include:

- Turning off the unit's exhaust system when the degreaser is covered so that vapors are not unnecessarily drawn from the tank.
- Ensuring that when adding solvent the flow is slow enough that splashing is prevented.
- Being careful to avoid overloading the degreasing tank.
- Racking parts for thorough drainage.
- Storing both fresh and used solvent in closed containers.

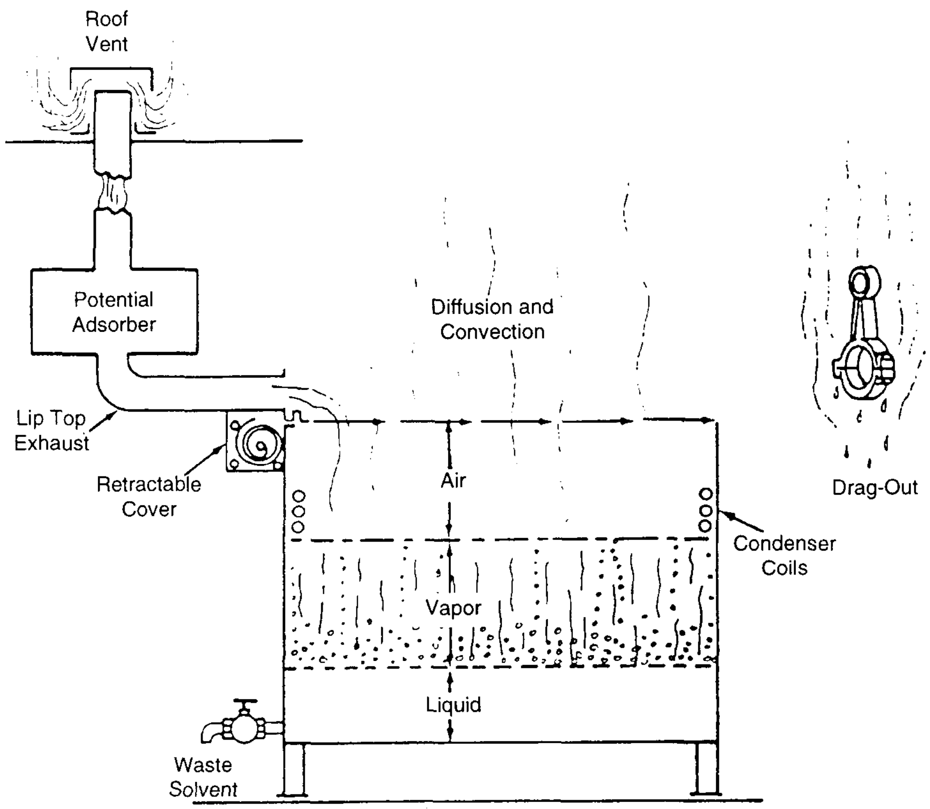

Figure 5-l. Schematic of a typical solvent vapor degreasing process (6).

- Adding a refrigerated freeboard chiller, either above or below freezing, which in some situations can yield control efficiencies of 40 percent.
- Ensuring that the degreasing tank is not undersized.
- Minimizing agitation of the liquid solvent.
- Designing the degreaser cover to be below the cross-ventilation ports at the top of the tank.
- Covering the degreaser tank whenever possible, particularly when not in use; in some cases, keeping the tank covered while the parts are suspended in the vapors by be feasible.

5.3.1.3 Operational Strategies Involving the Use of Conventional Vapor-Solvent Degreasers

Depending on the particular coatings operation, some facilities may be able to comply with near-term air quality regulations by using perc, methylene chloride, or trichloroethylene as a vapor degreasing solvent (8). All three are cost-effective alternatives to CFC-113 and 1,1,1 trichloroethane, which are ODCs, and none of them is currently being considered for phasing out. Moreover, they can be used in conventional degreasing equipment with little or no retrofitting (2). Table 5-2 presents chemical formulas of vapor degreasing solvents along with their respective boiling points. Solvents with a higher boiling point condense faster when they enter the lower temperature of the degreasing tank headspace.

Table 5-2. Relative Boiling Points of Principal Degreasing Solvents (9)

Compound	Formula	Boiling Point (°F)
Methylene chloride	CH_2Cl_2	104
1,1,1 Trichloroethane	CH_3CCl_3	165
Perchloroethylene	$Cl_2C{=}CCl_2$	250
Trichloroethylene	$CCl_2{=}CHCl$	188
CFC-113	$C_2C_{13}F_3$	180

Although emissions from these alternative solvents are generally considered less damaging to the atmosphere than conventional formulations, their use is controlled under various regulatory standards:

- Perc is considered a VOC as well as a HAP, and restrictions on its use have been proposed by the EPA under the Clean Air Act. Perc is recommended as a degreasing solvent over both methylene chloride and trichloroethylene because it has a higher boiling point, making vapor emissions easier to control. Generally, facility operators that use perc can keep emissions below 50 ppm, the threshold limit value (TLV) established by the American Council of Governmental Industrial Hygienists (ACGIH).

- Methylene chloride, a suspected carcinogen, is regulated as a HAP under the Clean Air Act. Although not considered a VOC due to its negligible photochemical reactivities, OSHA is seeking to lower its permissible exposure level (PEL) from 500 ppm to 25 ppm. Moreover, methylene chloride is covered along with perc by EPA's proposed NESHAP for solvent degreasing.
- Trichloroethylene is regulated as a VOC and a HAP under the Clean Air Act.

More generally, if the state permitting authority determines that an operation submitting an application for one of these solvents is likely to exceed federal or state TLVs, the facility may be considered to come within the "major source" category under Titles III and V of the Clean Air Act.[2] Air quality control requirements for facilities in this category can increase the cost of operation. For instance, a major source facility might be required to install emission abatement devices such as thermal or catalytic oxidizers, zeolite adsorbers, or biofilters. Thus, facility operators should perform a thorough analysis of the "potential to emit," as defined in Titles III and V, before switching to one of these alternatives.

Some of the available alternative degreasers include:

- HCFC-141b: Although this solvent, manufactured by Allied Signal, is a VOC, it has a low ozone-depleting potential. Nonetheless, it can only be used in cleaning operations through 1996 and only at facilities where it has been in use since late in 1994. Complete phaseout of the solvent is scheduled for 2002.
- HCFC-225: This solvent, manufactured by AGA Chemicals, has an even lower ozone-depleting potential than HCFC-141 b and can be used until 2020, at which time it will be banned from use.
- *HCFC-123:* This solvent, manufactured by DuPont, appears to offer low toxicity; however, it is not in wide use.

Additional possible interim strategies include:

- Use HFCs for vapor degreasing and drying until December 31, 1999, after which the HFCs must be replaced.
- Use a relatively nonvolatile solvent for cleaning and an HFC solvent for drying until December 31, 1999, after which the HFCs must be replaced.

The best long-term strategy may be to switch to a degreaser that does not emit HAPs. Numerous aqueous and semi-aqueous degreasers are currently available, and others are in development. Although for certain high-value processes the effectiveness of present formulations as replacements for solvent degreasers has yet to be demonstrated, many facility operators are likely to find them well suited to their needs. One limitation is that aqueous degreasers generally require a multiple-step process (i.e., cleaning then rinsing) followed by drying in a high-temperature oven. As a result, capital costs can be higher. Aqueous and semi-aqueous formulations are discussed in detail in Section 5.4.

Also in development are HFCs that neither deplete the ozone nor are considered to be VOCs due to their negligible photochemical reactivity to the atmosphere. The challenge for researchers will be to formulate a degreaser that has both good substrate cleaning and thorough drying characteristics. Some of these alternative solvents are expected to be available before the end of the decade.

One encouraging development concerns perfluorinated carbon compounds (PFCs) that contain only carbon and fluorine and are considered to be neither VOCs (smog formers) nor ODCs. These compounds may be developed for use as alternative drying agents. PFCs are more volatile than l,l,l trichloroethane and CFC-113 and thus would serve as an ideal replacement for operations in which fast drying is mandatory (e.g., for workpieces with complex geometries). Although there are concerns that these compounds contribute to global warming, EPA has approved them for the Significant New Alternatives Program (SNAP) 1.

More generally, if facility operators follow the proposed NESHAP for halogenated solvents, they should be able to run their processes well within OSHA requirements and easily meet permit limits.

5.3.2 Degreasing With Liquid Solvent (Cold Cleaning and Solvent Wiping)

5.3.2.1 Introduction

Solvents in liquid form are widely used for degreasing workpieces before applying a primer-topcoat system. This method-often called cold cleaning because the solvent is unheated, in contrast to vapor degreasing-involves bringing workpieces into direct contact with a solvent, such as methyl isobutyl ketone (MIBK), methyl ethyl ketone (MEK), or 1,1,1 trichloroethane (Table 5-3).

The great advantage of degreasers in liquid form is their versatility. They can be used to clean entire workpieces by immersion or spray washing (i.e., cold cleaning), for instance, or to clean selected areas of a component using rags, brushes, or cotton swabs (i.e., solvent wiping). Figure 5-2 illustrates a typical cold-solvent cleaning process.

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[2] Under Title Ill, a major source is one that has the potential to emit greater than 10 tons per year (tpy) of a single HAP or greater than 25 tpy of more than one HAP. Under Title V, a major source is one that has the potential to emit greater than 100 tpy of VOCs, greater than 10 tpy of a single HAP, or greater than 25 tpy of more than one HAP. Under both Title Ill and V, other conditions also can apply to qualify a source as "major."

Table 5-3. Typical Organic Solvents Used in Degreasing Operations

Solvent Group	Examples
Alcohols	Isopropanol, methanol, ethanol, isobutanol
Ketones	Acetone, methyl isobutyl ketone (MIBK), methyl ethyl ketone (MEK)
Ester solvents	Ethyl acetate, isobutyl isobutyrate, isopropyl acetate, glycol ether acetate
Aliphatic solvents	Hexanes, mineral spirits (made up of many different aliphatic petroleum fractions), heptane and higher molecular-weight fractions
Aromatic solvents	Toluene, xylene
Chlorinated solvents	Methylene chloride, trichloroethylene, 1,1,1 trichloroethane, perchloroethylene
Fluorinated solvents	Freons (chlorofluorocarbons) (a wide range is available; CFC-113 is the most widely used for degreasing)

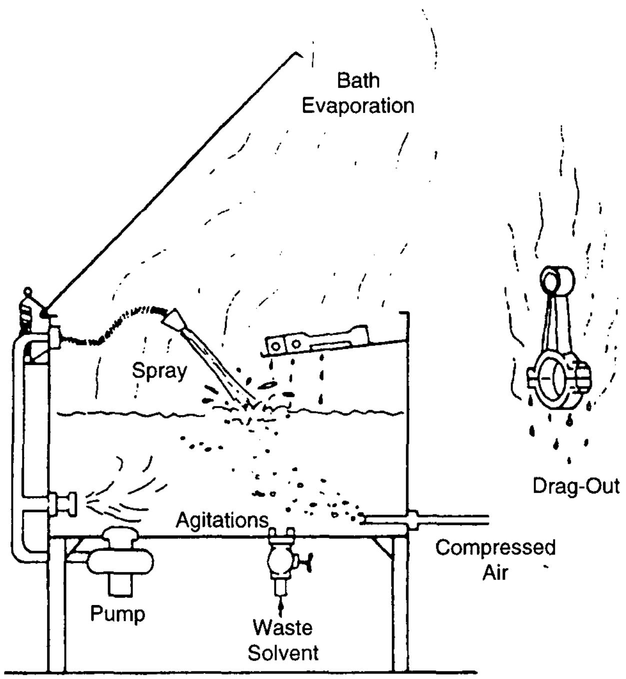

Figure 5-2. Schematic of a typical cold cleaning degreasing process (6).

In general, these approaches are effective for dissolving a wide range of oils, greases, and waxes, particularly on metal substrates but also on certain high-performance plastic workpieces with solvent-insensitive components. Like vapor degreasing, capital costs for cold-solvent cleaning operations are generally low, given minimal requirements for equipment, floor space, and training. Additionally, spent solvent can be easily distilled and recycled on site. In states where typical cleaning solvents are regulated as a hazardous material, however, most facility operators send exhausted cleaning solutions off site to commercial operations. These vendors typically recycle the spent solution and sell the recycled solvent at low cost.

As with vapor degreasing, the principal limitation of cold cleaning is that emissions from conventional solvents can be damaging to the environment and may pose a threat to human health. Other limitations of this approach include:

- If the solvent evaporates from a metal workpiece too quickly, atmospheric moisture can condense on the substrate and promote corrosion.
- Some solvents, especially after they have been recycled, leave a residue on the substrate that can undermine coating adhesion.
- Solvents with low flashpoints can cause fires or explosions.

Given that vapor degreasing is generally more thorough, facility operators typically opt for the cold-solvent cleaning approach when residues on the workpiece can be tolerated and costs are a critical factor.

5.3.2.2 Process Basics and Best Management Practices

Typically, cleaning workpieces with a liquid solvent involves one of the following approaches:

- Immersing the workpiece into a solvent bath
- Spraying the workpiece with solvent at low pressure.
- Wiping/scrubbing the workpiece with a brush/brush dipped in solvent.

Facility operators also use liquid solvent to clean coatings application equipment, such as spray guns. The cold cleaning method is used predominantly, however, to clean small workpieces, such as parts, rather than workpieces with expansive and complex geometries.

Cold-solvent cleaning systems should be configured to catch as much solvent as possible as it drains from the workpiece. Thus, when the operation involves immersion or spraying, the workpiece should be allowed to drain over the solvent tank for a minimum of 15 seconds or until it is visibly dry. Wiping or brushing operations should be carried out such that solvent drains back to the tank for reuse.

As in vapor degreasing, solvent emissions should be kept to a minimum in cold cleaning operations that the cleaning formulation is not exhausted unnecessarily. For this reason, solvents with low vapor pressures and high boiling points are preferred. Also, the solvent tank should be covered when not in use and the tank should be regularly checked for leaks using a halon detector. Facility operators must weigh the cleaning effectiveness afforded by either adding agitation to the immersion step or increasing the spray impingement against the resulting loss of solvent to evaporation.

Solvent vapors that are emitted during cleaning operations can be captured using an exhaust system with low vacuum pressure, to avoid drawing vapors off the surface of the tank. When substrate cleaning specifications necessitate the use of a relatively volatile solvent (e.g., toluene and xylene in wipe cleaning operations), the tank should be equipped with chiller coils that capture vapor and drain the condensed solvent back to the tank.

Best management practices for enhancing process efficiency in the cold-solvent cleaning operations include the following:

- For thorough immersion cleaning, a facility operator should provide additional solvent tanks rather than overload a single tank.
- To minimize emissions and ensure efficient solvent use, cleaning operations should be conducted in an enclosed area; if solvent is heavier than water and not miscible, a water cover (i.e., a shallow layer of water on top of the solvent) should be used as a vapor barrier: tank solvent should be replenished using an enclosed pumping system.
- To manage contaminated cleaning materials effectively, any solvent-laden rags should be stored in closed containers and specially permitted laundries should be hired to recycle solvent from rags; when disposing of rags as hazardous waste, they should be kept separate from other wastes for cost advantages.
- To control drag-out, workpieces that have porous substrates, which tend to entrap solvent, should be degreased by aqueous or semi-aqueous methods.

5.3.2.3 Operational Strategies Involving the Use of Conventional Liquid Solvents

Facility operators are strongly advised to consider switching to aqueous degreasers when workpiece specifications make such alternatives feasible. For situations where the use of aqueous formulations would not be appropriate, operators should investigate the effectiveness of solvents that have a high boiling point (i.e., low vapor emissions) and that are not VOCs, HAPs, or ODCs.

5.4 Aqueous Methods

Degreasing with aqueous-based solutions represents an attractive alternative to solvent-based methods. Both aqueous and semi-aqueous formulations are less toxic than conventional solvents and their ability to remove stubborn surface contaminants has been well established throughout the industry. (Appendix A presents a selected list of aqueous and semi-aqueous products on the market, along with information on their recommended use.) Despite the need for facility operators to include rinsing and drying steps for aqueous cleaning, many have found these formulations to be cost-effective alternatives because capital outlays associated with pollution prevention can be minimized. Moreover, like solvents, the versatility of aqueous solutions make them adaptable to a variety of degreasing approaches (e.g., in an immersion tank; in a heated, high-pressure spray).

To achieve maximum effectiveness when using aqueous-based formulations, it is particularly important for facility operators to fully understand process basics and recommended practices. For instance, even when using these less-toxic degreasers, facility operators will need to address some waste management and pollution prevention issues. Thus, this section discusses aqueous and semi-aqueous methods in the context of process efficiency, while touching on potential limitations associated with these alternative formulations.

5.4.1 Aqueous Degreasing

5.4.1.1 Introduction

Aqueous degreasing is by far the most common method for cleaning small parts and large workpieces before they are painted. Numerous facilities that for many years have relied on vapor degreasing and cold-liquid cleaning methods have converted to aqueous and semi-aqueous methods, primarily because they minimize concerns about pollution.

Aqueous degreasers include a base (e.g., sodium hydroxide), water, and one or more other ingredients (i.e., saponifiers, surfactants, chelating agents, corrosion inhibitors, or acidic or alkaline agents). By enhancing the properties of water that make it a universal inorganic solvent, these formulations are able to remove oils, greases, waxes, and similar organic compounds through solvation, detergency, and/or chemical reaction.

Because chemical compounds used in aqueous degreasers are less volatile and for the most part are not considered VOCs or HAPs, these cleaning formulations are subject to less-stringent regulatory constraints. Given that less, if any, air pollution is generated by aqueous degreasing operations, this cleaning approach is regarded as a cost-effective alternative for the longer term. A list of general advantages and limitations associated with aqueous degreasing is presented in Table 5-4.

The primary distinction between various aqueous degreasing formulations is whether they are acid or alkaline based. A selected list of both types of cleaners is presented in Table 5-5. Generally, acid-based degreasers are more active formulations and thus are preferred for removing corrosion and scale from metal

Table 5-4. Considerations for Aqueous Degreasing

Advantages	Disadvantages
Does not emit solvent vapors (VOCs, HAPs, or ODCs) into the air	Requires more floor space than vapor degreasing or cold-solvent cleaning operations
Removes most contaminants (e.g., oils, greases, hydraulic fluids) and more stubborn contaminants (e.g., smut, metal fines) if agitation is used	Cannot be used to clean parts that are moisture sensitive (e.g., assembled electronic components)
Can be used in batch or continuous operations	Usually requires a dry-off oven, which consumes energy; inadequate drying can promote flash rusting
Well suited to cleaning processes that will be followed by a phosphate coating	Large parts may be more difficult to clean
A dry-off oven may not be necessary if the parts will be coated with a water-borne coating (e.g., electrocoating)	Operator may need to experiment with various degreasing chemicals if stubborn deposits are not easily removed
Monitoring of chemicals is not complicated; process includes a pH check and control of temperature, processing time, agitation in the form of air sparging (for immersion tanks); good impingement (for tunnel systems)	Poor rinsing can contribute to paint failures
Can be used for all types of parts, regardless of whether they are solvent sensitive	Additional quality control is required (in contrast to vapor degreasing) if surfaces must be especially clean
	Water may collect in channels and pockets, from where it may not thoroughly evaporate
	Water and degreaser may get between overlapping joints on certain workpieces and later seep out and mar the coating if inadequate oven drying is carried out
	Metal surfaces, which are slightly alkaline after degreasing, must be neutralized with an acidic solution (e.g., a phosphate coating) before paint can be applied
	Wastewater must be treated before it can be disposed

Table 5-5. Selected Aqueous Degreasers (1)

- Ammonium hydroxide, potassium hydroxide, sodium hydroxide
- Diethylene glycol monobutyl ether
- Dodecanedionic acid
- Ethylenediaminetetra-acetic acid (EDTA) and its tetrasodium salt
- Monoethanolamine, diethanolamine, triethanolamine
- Borax
- Sodium carbonate
- Sodium gluconate
- Sodium silicate, sodium metasilicate
- Sodium tripolyphosphate, trisodium phosphate, tetrasodium phosphate, tetrapotassium pyrophosphate
- Sodium xylene sulfonate
- Water (tap, deionized, steam)

workpieces. In contrast, because they are somewhat milder, alkaline formulations are recommended for cleaning plastics as well as certain metal substrates, such as aluminum, particularly when the corrosivity of acid degreasers is a concern. Alkaline solutions can effectively remove such contaminants as oil, grease, and waxy films. Because both types of formulations are corrosive, cleaning system operators must take precautions, such as wearing protective equipment, to avoid sustaining chemical burns.

Although acid degreasing is more effective for certain substrates, the corrosivity of acid compounds necessitates the use of more expensive containment equipment and additional maintenance. For instance, to prevent corrosion of immersion tanks, they must be lined with rubber or plastic or made of stainless steel. Indeed, inhibitors are often added to the degreasing solution to prevent the corrosion of tanks. These formulations also solubilize heavy metals from substrates and etch steel, thus generating more sludge that must be disposed of as a hazardous waste. Moreover, because acid cleaners can cause hydrogen embrittlement of the substrate, this approach should not be used for workpieces made of high-tensile steel. Finally, without thorough rinsing or the incorporation of inhibitors, acids in the cleaning solution can promote corrosion of the finished workpiece.

Alkaline formulations are not without their limitations, however. For example, trace alkalinity may be difficult to rinse from the workpiece. Also, certain substrates, particularly on some electrical components, may be subject to corrosion under alkaline, rather than acidic, conditions.

Aqueous degreasing generally allows facility operators to avoid costs associated with pollution prevention, particularly air emissions control devices. Capital equipment and process requirements, however, can add to operation costs. In contrast to one-step solvent approaches, aqueous degreasing involves at least a two-step process in which acidic or alkaline residues are rinsed from the workpiece following degreasing. More often, however, operators use a three-step system that includes drying the rinsed workpiece in an oven before applying paint or a pretreatment coating. (For detailed discussions about phosphating and rinsing, see Chapters 6 and 7, respectively.)

5.4.1.2 Process Basics and Best Management Practices

Typically, aqueous degreasing operations involve subjecting workpieces to the cleaning solution either through immersion or pressure spraying. The most basic process includes a cleaning step followed by rinsing that adjusts the pH level of the substrate by removing acidic or alkaline residues. The system should be configured to allow the degreasing solution to thoroughly drain from the workpiece, thus minimizing drag-out into the rinsing bath. Proper draining of workpieces also facilitates efficient use of the cleaning solution. Following immersion, a workpiece should be allowed to drain while suspended over the tank: in spray operations, a containment system should be used to channel drainage back to the feed source. Both immersion and spraying lend themselves to automation.

An advantage of aqueous degreasing over the liquid solvent method is that agitation can be readily added to the immersion process, given that the cleaning solution is less volatile and therefore less likely to evaporate. Agitation is particularly recommended for cleaning either workpieces with complex geometries (e.g., with recesses or threaded sections) or numerous small parts at one time. The immersion approach in general is advantageous when floor space is limited.

Some facilities enhance the effectiveness of conventional spray cleaning operations by using either super-heated steam or high-pressure hot water. Both approaches, loosely referred to as steam cleaning, involve a pumping system that mixes heated water with the cleaning solution and delivers it via a hose to the spray wand. In general, steam cleaning is used on workpieces that are too large to fit in an immersion tank or to pass through a conveyorized spray system. The major disadvantage of such cleaning methods is that they consume large amounts of water, which must be treated before being discharged to a publicly owned treatment works.

For true steam cleaning, water is typically heated to approximately 230°F (i.e., well above the boiling point of water') and the super heated steam is sprayed at a pressure of 50 to 150 psi. Steam can be effective for removing particularly stubborn contaminants. This approach also is recommended for minimizing water usage and promoting rapid drying of the substrate. The principal disadvantage of this approach is that line operators can be scalded easily by super heated steam, in part because it is nearly invisible as it comes off the spray wand.

High-pressure hot water spraying reduces the likelihood of worker injury because the water is heated to a temperature below the boiling point and sprayed at pressures ranging from 50 to 100 psi. Despite the lower temperature of the water, this approach, which includes use of a soap detergent typically drawn from a 55-gallon drum, can be highly effective for removing many of the same deep-seated contaminants from a substrate. (The appropriate concentration of the detergent should be based on the manufacturer's recommendation.) Additionally a system can be set up in which a single spray wand is used to clean and rinse a workpiece and then, for a metal substrate, apply a mild phosphate coating. In such a system, the process operator can control a valve that shuts off the degreaser formulation feed and turns on the phosphate feed. As with the degreaser, the phosphate typically is siphoned from a 55-gallon drum. After applying a low-concentration phosphoric acid (e.g., 2 oz/gal) to the workpiece and allowing for a 45 to 60 second contact time, the operator can give the piece a final rinse with clean, hot water.

The following factors apply with this approach to phosphating (see also Chapter 6 for an extensive discussion of phosphate deposition considerations):

- Phosphoric acid should be syphoned directly to the wand rather than to the hot water heater, where it might encourage corrosion of the heating coils.
- The light phosphate coating deposited with this method can provide only short-term protection (several hours) against flash rusting; it should not be compared with conventional iron or zinc phosphates, which provide conversion coatings with significantly greater corrosion resistance.
- Despite deposition of the phosphate coating, the workpiece should be dried quickly to avoid potential flash rusting, especially on workpieces with complex geometries.
- Whereas blow drying is recommended, the process operator should ensure that moisture or oil is not conveyed to the workpiece with the ambient air coming from the compressor. The blower system's oil and moisture traps should be checked frequently.
- Because phosphate cannot form over scale or rust, in some cases the deposited coating will provide little corrosion protection for hot rolled steel with such contaminants on the substrate. The acid will neutralize, however, any alkalinity that may remain on the substrate after alkaline degreasing-a critical parameter for adhesion of the primer coat.

Regardless of the aqueous cleaning approach used, such operations generate wastewater that must be treated before being exhausted to a publicly owned treatment works. Generally, spent washwater is dumped or drained into a settling tank. Oil and grease that rise to the top are skimmed off and usually either 1) sent off site to be blended into a fuels that can be thermally oxidized or 2) disposed of as a liquid hazardous waste. Contaminants pumped out from the bottom often are passed through a filter press, dried into a cake, and then disposed of as a solid hazardous or nonhazardous waste, depending on the characteristics. In some cases, the dried sludge is used as an inert filler in other operations. The remaining water is treated for pH adjustment and then either discharged to the treatment works or dumped into a shallow holding pond, where it is allowed to evaporate. Many large facilities have begun recycling all of their process water to the cleaning operation following onsite treatment. In this way, many such facilities are seeking to achieve closed-loop operations.

Best management practices for enhancing process efficiency in the aqueous degreasing operation include the following:

- For thorough cleaning:
  - Experiment with different aqueous degreaser products and contact several vendors to identify the formulation best suited to particular workpieces.
  - Test the entire range of degreasers recommended by a vendor because solution formulation and temperature can alter cleaning efficiency.
  - Ensure that batches of parts immersed in the degreaser are properly positioned to avoid overlap and to minimize drag-out.
- For cost effectiveness:
  - Raise the temperature of the degreasing solution and the rinse water to avoid the expense associated with removing flash rusting, especially in operations that do not include a drying oven. (The facility operator should keep in mind, however, that heating the degreaser will add to energy costs somewhat.)
  - Compare costs of powdered and liquid degreasing formulations.
- For process efficiency:
  - Purchase degreaser and phosphate formulations from the same vendor to avoid compatibility problems.

5.4.1.3 Process Variations

Two-Step Process

A two-step aqueous degreasing process involves cleaning and then rinsing the workpiece, usually with tap water. In a paints and coatings operation, this basic system for degreasing might be used, for example, between application of the primer and the finish coat. Such a process might be used when primed workpieces will be stored outdoors for weeks or months before being used in the assembly of a finished product. Degreasing would be performed immediately before application of the topcoat to remove any fingerprints and general grime, industrial oils, or hydraulic fluids deposited on workpiece surfaces. After degreasing, the workpieces then could be left to dry in the ambient environment, particularly pieces that incorporate electronic components or heat-sensitive materials. Flash rusting is not a concern at this stage because the piece has already received its primer coat. Alternatively, the workpieces may be dried using air knives (i.e., targeted jets of warm air) or by subjecting the pieces to blasts of clean, dry compressed air.

Contaminants in tap water, however, can undermine the long-term corrosion-resistance of a finished piece. Thus, a single tap-water rinse is recommended only for low-value products in price-sensitive markets or products that will not be used in humid or corrosive environments.

Three-Step Process

In a three-step process, the degreaser is followed by at least one tap-water rinse and then rinsing with deionized water. The use of deionized water is recommended when the workpiece will undergo phosphating after degreasing and a high-quality phosphate coating must be achieved to ensure a high-value finished piece.

If a high-value workpiece will not receive phosphating pretreatment, the piece might need to be dried, following rinsing, in an oven at a temperature ranging from 260^{o} to 400°F. The higher end of the temperature range for dry-off is not recommended, however, for alloys that might undergo a phase transformation, for machined parts that must meet especially high tolerances, or for components that include heat-sensitive materials. Other considerations include the cost of firing the drying oven at sustained high temperatures and the time required for workpieces to cool, especially heavy castings, before being moved along in the process.

Four- and Five-Step Processes

Operations applying a primer-topcoat system to high-value workpieces that must be thoroughly cleaned before a phosphate coating is applied often provide additional rinse steps at the degreasing stage. For example, operations in the automotive and appliance industries typically rinse workpieces in one or two baths of deionized water after the tap-water rinse step. Along with ensuring proper adhesion of coatings by minimizing surface contaminants, these additional rinse steps also extend the useful life of conversion coating baths by minimizing degreaser drag-out. For superior corrosion resistance, the conversion coating must be deposited on a slightly acidic surface (i.e., in the range of 5 to 6 pH). (For a detailed discussion of rinsing operations, see Chapter 7.)

5.4.2 Semi-aqueous Degreasing

5.4.2.1 Introduction

Semi-aqueous degreasers represent a middle ground between the use of solvent-based and aqueous approaches. They are more effective than strictly aqueous formulations for removing heavier grease, wax, and even tar from a variety of substrates (i.e., metal, ceramic, plastic, and elastomer); however, because these formulations include volatile ingredients-albeit with low vapor pressures and high boiling points-they are regulated as VOCs, HAPs, or ODCs. Semi-aqueous mixtures are based on organic compounds, such as terpenes and alcohols, and thus are somewhat less threatening to the environment and human health than most conventional solvent degreasers. The cleaning mechanism for semi-aqueous degreasers is essentially the same as for aqueous degreasers. Table 5-6 lists typical organic constituents used in semi-aqueous degreasers.

An additional advantage of semi-aqueous over solvent degreasers is that they generally have a higher flashpoint and lower volatility than organic solvents; thus, they are less prone to combustion and evaporation, making them applicable in both spray and immersion processes. Moreover, because such formulations tend to be characterized by low surface tension, they are particularly effective on workpieces with surface features that are difficult to clean, such as small holes and crevices.

A principal limitation of semi-aqueous degreasers is that they are highly flammable when in a concentrated gaseous form, especially formulations based on terpenes. For this reason, they should never be heated above 90°F. Flammability can be minimized, however, by formulating or using them in their emulsion form. Additionally, certain formulations can cause plastics and elastomers to swell.

5.4.2.2 Process Basics and Best Management Practices

Degreasing operations using semi-aqueous formulations are conducted in the same way as aqueous cleaning. The basic process involves two steps-degreasing, either by immersion or spraying, followed by a tap-water rinse to remove residues.

Table 5-6. Typical Organic Constituents in Semi-aqueous Degreasers (3)

Constituent	Comment
Terpenes	Derived from citrus and pine oils; can be formulated into emulsions; new formulations raise flashpoint to >144°F providing cleaning effectiveness and reducing danger of fire or explosion; effective at low temperatures; often can be recycled
Esters	Most common are aliphatic mono esters (primarily alkyl acetates) and di-basic esters (DBEs); can be used cold or heated; favorable solvent properties but poor solubility in water; flashpoint usually >200°F; can be slow drying
Glycol ethers	Generally divided between e- and p-series, with neither considered a HAP; favorable solvent properties and effective as emulsion in water; can remove polar and nonpolar contaminants; easy to recycle; flashpoint usually to >200°F
N-methyl-2-pyrrolidone (C_5H_9NO)	High solvency and effective on many contaminants; completely soluble in water and other liquids; can be used cold or heated: flashpoint is approximately to 199°F
Ethyl lactate	Can be used as for cold-liquid degreasing; a VOC, but not considered a HAP or an ODC; has a favorable evaporation rate

For a more extensive discussion of semi-aqueous degreasers, see EPA's *Guide to Cleaner Technologies: Alternatives to Chlorinated Solvents for Cleaning and Degreasing* (3) (see also Reference 5).

5.5 Case Examples

5.5.1 Frame Manufacturer

A large manufacturer purchased oil-free and pickled steel for fabricating frames to be used in heavy machinery. Despite the higher cost, managers believed they would be able to produce a better and longer-lasting product. A few months after switching to the treated steel, however, they experienced a spate of catastrophic paint failures. It appeared that the frames would have to be recalled and then stripped, cleaned, and repainted.

In the original process, after fabrication the frames were moved into a washing room where all workpiece surfaces were thoroughly cleaned with a high-pressure hot-water degreaser using a wand. Because the frames were long and wide, the left side was cleaned before the right. In the first pass along the left side, the hot water incorporated a soap solution. In the second pass, the frame was rinsed with municipal tap water at ambient temperature. The line operator then repeated the process on the right side of the frame. After the entire cleaning operation was completed, the frame was stored outside where the surfaces were left to dry at ambient temperature.

Due to the size of the frames, the entire degreasing process took 1 to 1.5 hours. By this time, the entire workpiece was covered in flash rust. The production manager, unaware of the situation, allowed the primer and topcoat to be applied over the rusted surfaces. Only after several frames were rejected because of catastrophic failures in the field did managers call in a consultant to investigate the cause of the problem. They found that several poor practices contributed to the paint failures:

- During the first pass along the right side of the frame, the fine overspray of detergent solution from the spray wand was contaminating the already-cleaned surfaces on the left side.
- Because the first stage was hot (approximately 180°F), the detergent solution from the first stage evaporated from the frames, leaving a residue of alkaline soap on the surface.
- The frames were rinsed with municipal tap water that had a high concentration of minerals (i.e., dissolved salts). When the water evaporated, the minerals

remained on the surface and thus were available to promote corrosion under the topcoat of paint.

- Because the original milling oils had been removed from the steel surfaces during the degreasing operation, the metal was more sensitive to flash rusting. This was aggravated by the slow evaporation rate of water at ambient temperatures.

The managers were advised to abrasive-blast clean the metal surfaces to a near-white finish (see Chapter 8) and then apply a corrosion-resistant primer within 4 hours. The company, however, could not justify the expense of installing a blast cleaning room. Instead, the managers made the following changes to their process:

- Two workers were assigned to perform the degreasing operation so that the metal surfaces at the front end of the frame would not dry while the back end was still being degreased.
- Surfaces were kept wet until the final rinse had been accomplished.
- Deionized rinse water was used to avoid contamination by dissolved salts in the municipal tap water.
- The deionized water was heated to approximately 180°F to accelerate the drying process and thus avoid the need for a drying oven.
- To minimize water usage and the disposal of excess contaminated water, the rinse stage was recycled through an ion exchange resin in the deionized water generator.
- The company's production office rescheduled work so that the frames could be moved directly from the washing room into the primer spray booth. (Cleaned frames were not stored outside unless they had been primed.)

The frames that were rejected due to flash-rusting underwent paint stripping operations and then were repainted. The cost of this approach was quite high because contractors were required to disassemble the end-products to process the failed frames.

5.5.2 Military Contractor

A large military contractor in the Midwest was using approximately 250,000 pounds per year of 1,1,1 trichloroethane to degrease primarily aluminum parts prior to welding. The company was participating in EPA's 33/50 program, which encourages a use reduction for selected hazardous chemicals by 33 percent by the end of 1992 and a further 50 percent by the end of 1995. Thus, managers decided to totally eliminate their use of 1,1,1 trichloroethane by installing an aqueous degreasing washing cabinet.

Given the vast number of part configurations needing to be cleaned, a highly sophisticated system was purchased. The cabinet included a rotating table, high-pressure spray nozzles, the ability to add an inhibitor to the rinse water, and the option to add more than one rinse, depending on the complexity and configuration of the parts. The system is a closed loop, ensuring that the large amount of water used is treated in an ultrafiltration unit and then recycled.

Military specifications needed to be followed in the manufacture of the end-product, requiring that the contractor obtain approval before changing the degreasing process. The military client, however, also was interested in eliminating the use of 1,1,1 trichloroethane and readily approved the change.

5.5.3 Lift Truck Manufacturer

A lift truck manufacturer with a solvent-based degreasing operation for cleaning cutting oils and metal fines, primarily from aluminum parts, decided to switch to an aqueous degreaser. The incentive, in part, was concern about exposure of line operators to harmful emissions.

The principal solvent being used by the company for vapor and cold cleaning was 1,1,1 trichloroethane. Before switching degreasing formulations, the company tested approximately 30 different aqueous degreasers, comparing their effectiveness to the 1,1,1 trichloroethane. Eventually, the company identified an aqueous degreaser that was more effective for removing stubborn surface contaminants than the 1,1,1 trichloroethane.

When the company evaluated their cleaning operations for both small parts (primarily screw machine parts) and larger workpieces with complex geometries, managers found that both types of workpieces could be effectively cleaned by immersion in a tank of agitated aqueous degreaser. For the smaller parts, an additional advantage of the process change was that it allowed the company to combine degreasing with the removal of burrs as a result of bath agitation. For the larger parts, managers were able to identify a degreaser that would be effective on the aluminum workpieces as well as the occasional copper and cast iron pieces. Following degreasing, the workpieces were rinsed in a solution containing a corrosion inhibitor and then were blown dry.

Conversion to aqueous degreasing reportedly saved the company about $102,000 per year, at the same time that toxic emissions were essentially eliminated. The majority of savings resulted from more efficient use of the cleaning formulation, given that a batch of aqueous degreaser includes only 5 to 10 percent cleaning solution, with the balance being water.

Over the past decade, EPA and state officials have been encouraging companies to evaluate their processes and consider switching to degreasing approaches that generate less pollution. As a result, many companies have discovered that they have been clinging to old and inefficient practices. By updating their operations, many realized significant process efficiencies and even enhanced the quality of their finished products.

This case example emphasizes the importance of testing numerous degreasers from more than one vendor before making a change. Because no universal degreaser exists-solvent or aqueous-that will remove all surface contaminants, often a degreaser must be matched to the specific operation. Thus, when switching degreaser formulations, a facility operator should always allow sufficient time to test available products.

5.6 References

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Chapter 6
Phosphating Metal Surfaces: Process Efficiency and Waste Minimization

6.1 Introduction

6.1.1 Pollution Prevention Considerations

For many paints and coatings operations, workpiece specifications do not require the superior adhesion and corrosion-resistance characteristics that can be achieved with a phosphate pretreatment step (i.e., depositing a conversion coating on a metal substrate in preparation for a primer-topcoat system). In such cases, phosphating may add costs that make the finished product less attractive to consumers in price-sensitive markets. Operations processing higher-value metal workpieces, however-for such products as automobiles, appliances, office furniture, and outdoor equipment-must include this step so that coatings meet requirements for long-term corrosion resistance.

Phosphating can add unavoidable costs associated with the operation and maintenance of an extended process line. The facility operator can minimize the generation of pollutants, however, and thus the cost of managing wastewater and sludge, if the phosphating process is conducted efficiently. Indeed, efficient phosphating not only minimizes waste generation and maximizes chemical use, it also ensures optimum deposition weight. This ultimately lengthens the life of the product. A principal consideration in phosphating is that formulations be appropriately matched to the particular metal substrate. Otherwise, the process will result in less-desirable pretreatment coatings and will generate an excess of heavy metal sludge. The expense of collecting and disposing of these hazardous materials can add significantly to overall processing costs.

Iron and zinc phosphating are the most widely used conversion coating approaches for steel substrates. Wash primers represent an alternative approach when conventional phosphating is not possible. Whereas these pretreatment-primer coatings can be used with minimal process costs, conventional high-VOC wash primer formulations raise significant concerns about air emissions. The less-volatile water-borne wash primers that have become available in recent years, however, represent a cost-effective alternative for certain types of operations.

Various approaches for phosphating are discussed in this chapter in the context of the process efficiency considerations that are critical to waste minimization. Although the emphasis in this discussion is on phosphate coatings for steel substrates, many of the recommended practices also apply to other metals.

6.1.2 Decision-Making Criteria

Decision-making criteria relevant to phosphating process efficiency and waste minimization, many of which are addressed in this chapter, are highlighted in Table 6-1.

6.2 Process Basics and Best Management Practices

6.2.1 Introduction

Phosphating (i.e., iron and zinc phosphating) is a process of depositing a conversion coating onto steel and galvanized steel to prepare the surface to receive a liquid, powder, or electrodeposited coating. The phosphate deposit is referred to as a conversion coating because it converts the surface of the virgin steel (no oxide present) to a roughened amorphous or crystalline phosphate composite (Figure 6-1). A phosphate deposit can enhance a paints and coatings application in essentially three ways:

- Serving as a barrier to keep atmospheric oxygen and moisture from attacking the base metal.
- Acting as a dielectric film that electrically insulates the substrate from the paint or other coating, slowing the process of galvanic corrosion.
- Providing a rough surface for mechanical gripping of the paint or other coating for an improved bond.

Establishing a strong bond between the primer-topcoat system and the substrate enhances the corrosion-resistance of the workpiece as well as the general resilience of the surface (1). Along with providing the foundation for this bond, however, this pretreatment step also plays another important role in promoting the durability of the finished piece. The phosphate coating acts as a secondary barrier against moisture and oxygen, inhibiting the

Table 6-1. Decision-Making Criteria Regarding Phosphating of Metal Surfaces

Issue	Considerations
Is the workpiece too large or is its geometry too complex for pretreatment in an immersion tank or a spray system?	• If yes, consideration should be given to the following approaches: #1 Use wand-operated steam cleaning with a detergent, followed by wand application of a mild phosphoric acid solution; a final rinse with clean municipal tap water may be necessary. #2 If the above approach is not feasible, consider wipe cleaning with an aqueous degreaser, followed by a second wipe cleaning with clean tap water; use of solvents should be avoided because they can cause unnecessary air and water pollution. #3 As a last resort: After degreasing metal surfaces, apply a thin coat of wash (acid etch) primer; the coating film thickness is usually controlled at 0.3 to 0.5 mil. This approach should be avoided because most wash primers contain high concentrations of solvents (typically with a VOCs content of 6.5 lb/gal, or 780 g/L) and thus raise air pollution concerns.
Is the workpiece small enough to go through either an immersion tank system or a spray washer system?	• If yes and the operation's production rate is relatively low (i.e., workpieces would proceed at about 2 ft/min), an immersion system should be considered. • If yes and the operation's production rate is higher (i.e., workpieces would proceed at **a** speed greater than 2 ft/min), a spray washer system should be considered. (Note: A rate of 2 ft/min is a guideline only. When designing a system, a facility operator should consult with an equipment vendor and conduct a process cost analysis.)
Will the topcoated workpiece be exposed primarily to noncorrosive environments? or Is the workpiece a low-cost product for a price-sensitive market such that adding the cost of pretreatment would undercut sales?	• If yes, then consideration should be given to the following approaches: #1 Use a three-step process in which the first step combines cleaning and phosphating, the second step is a tap-water rinse, and the third step is a rinse that includes a nonchromate rinse sealer. (A two-step process with a combined cleaning and phosphating step followed by only one rinse is ill advised.) #2 Use wand-operated steam cleaning with a detergent, followed by wand application of a mild phosphoric acid solution; a final rinse with clean municipal tap water may be necessary. #3 If the above approach is not feasible, consider wipe cleaning with an aqueous degreaser, followed by a second wipe cleaning with clean tap water; use of solvents should be avoided because they can cause unnecessary air and water pollution. (Note: None of these approaches yields a high-quality surface on which to apply paint.)
Will the topcoated workpiece be exposed to aggressive corrosive environments? or Is the workpiece **a** high-cost product (e.g., for the computer, automobile, or large appliance industry) sold in a market that is not especially price-sensitive?	• If yes, then at the least consideration should be given to a three-step pretreatment process; however, a process with five or more steps would be preferable. In these multistep processes, degreasing and phosphating are separate steps and each is followed by rinsing. (Note: In general, the quality and corrosion-resistance characteristics of a primer-topcoat system will improve as rinse steps are added.)
Do workpiece specifications emphasize corrosion resistance and long-term appearance?	• If yes, thenconsiderations should be given to the following approaches: #1 Apply a phosphate coating using zinc phosphate rather than iron phosphate for greater corrosion-resistance and appearance characteristics. This pretreatment process will require at least five steps. (A decision to use zinc phosphate should be well researched because this approach is more expensive and complex than alternatives.) #2 Apply a phosphate coating using iron phosphate; to achieve the specified quality, additional rinse steps may be required, with at least one deionized water rinse at the end.
Will phosphating be conducted with a zinc phosphate formulation, and will the workpiece require a super high-gloss finish (i.e., registering >95 percent on a 60-degree gloss meter)?	• If yes, then consideration should be given to using a microcrystalline zinc phosphate because small crystals will not detract from the gloss.
Do workpieces currently undergo phosphating and then receive a wash primer?	• If yes, then the wash primer can be eliminated since it is both unnecessary and may be harming the topcoat (e.g., causing blistering or corrosion under the paint film). Elimination of the wash primer step will dramatically reduce VOC emissions.
Does a line operator manually move workpieces from one tank to the next?	• If yes, the worker should be instructed to allow each workpiece to drain over the process tank before moving it to the next tank; training should also cover the importance of keeping draining time to a minimum to avoid the onset of flash rusting.

Table 6-1. Decision-Making Criteria Regarding Phosphating of Metal Surfaces (continued)

Issue	Considerations
Are workpieces automatically moved from one tank to the next via a computerized hoist crane?	· If yes, the system should be programmed to allow workpieces to drain over immersion tanks, while avoiding the onset of flash rusting. · If workpieces span a wide range of geometries, consideration should be given to programming the system for various groupings of workpieces.
Do workpieces pass through a conveyorized spray washer?	· If workpieces span a wide range of geometries, consideration should be given to programming the system for various groupings of workpieces. · The facility operator should conduct tests to determine the optimum conveyor system speed for allowing adequate workpiece draining (as opposed to changing the speed for different workpiece configurations).
Does the spray booth operator have access to the conveyor system on/off switch? And does the operator on occasion stop the system while workpieces are still wet?	· If yes, then consideration should be given to the following approaches: #1 The operator should be instructed not to stop the conveyor system until all workpieces have passed through the spray washer and the dry-off oven; it is likely that allowing a workpiece to remain above a tank or between stages will ultimately cause a paint coating failure. #2 Establish two separate conveyor systems: one that makes a loop around the spray washer and another that passes through the spray booths and the dry-off oven. The disadvantage of this approach is that the line operator must offload workpieces from the first conveyor and then load them onto the second system. #3 Install a power-and-free conveyor so that the speed of the conveyor as it passes through the spray washer can be faster than the speed of the second conveyor that passes through the paint booths and dry-off oven. This approach is more expensive than the others, but it allows workpieces to accumulate after leaving the spray washer and avoids the need for a line worker to offload and load workpieces, as required in approach #2.
What approach is recommended for selecting a phosphate formulation from the many that are available?	● The best approach is for the operator to test different formulations in the existing process line. Since this is usually not feasible, an alternative is to have several vendors phosphate test pieces, immediately after which a primer should be applied. Once the primer has cured, the coating should be tested for adhesion and then for corrosion-resistance characteristics in a salt spray (i.e., fog) chamber. These tests will identify the best formulation. ● Only by testing a formulation in the actual process line can the operator determine the typical useful life of a phosphating immersion bath. (Note: Generally it is not possible to make an assessment regarding the most appropriate phosphate formulation by reviewing vendor data sheets.)
Is it better to use a low- or a high-temperature phosphate formulation?	• In general, low-temperature formulations do not provide the same quality phosphate coating as high-temperature formulations. Thus, the tradeoff is between quality and energy costs.
What approach is recommended for selecting between powder and liquid phosphate formulations?	• A decision usually can be made on the basis of cost. Although powder formulations are generally less expensive, the operator must mix the phosphating solution according to vendor literature. In contrast, liquid formulations come ready for use, although some dilution with water may be required.

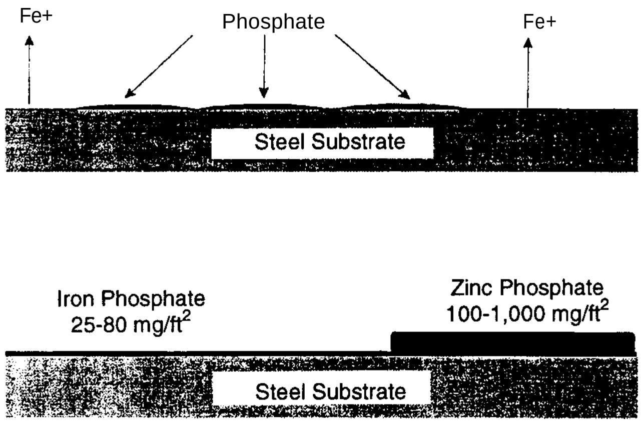

Figure 6-1. Cross-sectional view of conversion coating process using iron or zinc phosphate.

electrochemical process that leads to galvanic corrosion of the metal substrate.

This pretreatment step is specific to metal substrates. The phosphate coating process is not used on plastics or ceramics because neither can participate in an electrochemical -reaction as can metals. The deposition of phosphates only takes place if an electric current can flow through the substrate/liquid system (see Chapter 3 for a discussion of the electrochemical reaction that takes place in the corrosion process).

The discussion in this chapter primarily focuses on methods for applying a phosphate coating to steel, which typically is accomplished by bath immersion or spraying of the workpiece with an iron or zinc phosphate solution. These same phosphating methods also can be used on several other metals. For some substrates, however, processes specific to the particular metal must be used. Indeed, studies have shown that steel substrates are the most conducive to phosphating (2). Using a phosphating process that is inappropriate for a particular substrate can result in both a poor conversion coating and an excess of heavy metal sludge (see discussion on waste minimization in Section 6.4).

In the case of aluminum, phosphating chemicals occasionally are used to clean the substrate rather than to establish a conversion coating. The most popular conversion coatings for aluminum are based on chrome oxides. Historically, such coatings have provided corrosion resistance that is superior to that achieved with other aluminum pretreatments. Unfortunately, however, they contain hexavalent chromium (Cr6+), which is a hazardous heavy metal. For many years, the industry has sought to replace chrome oxides with less-hazardous pretreatments, and nonchrome alternatives are available for applications in which corrosion resistance is not critical for the finished piece. These alternative formulations have been slow to gain acceptance, however, from some operations. For instance, the U.S. Department of Defense (DOD) has only recently tested and found some of these nonchromate alternatives environmentally acceptable (3). Thus, before a particular nonchromate alternative is used on workpieces being finished under a DOD contract, the process operator should check to confirm that the formulation has been specifically approved (especially when the pieces are for the Air Force).

Despite the enhanced durability afforded by application of a phosphate coating, for many paints and coatings operations the addition of this pretreatment step is not cost effective. Many steel products for the building and construction industry (e.g., metal ties, brackets), for instance, are not required to have a high-quality organic finish. Indeed, the higher price that manufacturers of such products would need to charge to recoup the cost of additional pretreatment might undermine safes in this price-sensitive market. Similarly, the cost of phosphating particularly large workpieces can be preclusive. The alternative pretreatment approach for large structural members such as l-beams is abrasive blasting (see Chapter 8).

Phosphate coatings are applied primarily to higher-value goods or to products designed to provide long-term performance. In the appliance manufacturing industry, for example, both iron and zinc phosphating are used extensively to achieve high-quality primer-topcoat systems. As shown in Table 6-2, large and small parts alike receive this pretreatment at relatively high-production rates.

Table 6-2. Typical Spray Phosphating Production Rates in the Appliance Industry (1)

Part	Area (ft^2)	Pieces per Hour
Zinc Phosphate (150-200 mg/ft^2)		
Dryer shell	42.5	400
Cabinet backpanel	12.7	700
Base pan assembly	7.9	900
Timer mounting bracket	0.6	8,500
Iron Phosphate (40-80 mg/ft^2)		
Washing machine shell	52.9	330
Dryer top	12.7	660
Motor access panel	6.9	4,950
Conduit cover plate	0.31	8,900

6.2.2 Coating Quality and Basic Parameters

The quality of a phosphate coating is determined primarily by its weight (in milligrams per square foot) rather than its thickness. For optimum process efficiency, phosphate coatings should be weighed regularly and the results tracked over time. Allowing too heavy a phosphate coating to form on a substrate can ultimately lead to failure of the primer-topcoat system. For example, an excessive coating can eventually split and cause delamination of the topcoat.

Coating weight can be determined by immersing a preweighed, coated panel in a beaker containing heated chrome oxide. Results can usually be obtained within a few hours. Such a test, however, should only be conducted by a trained technician in a laboratory that is properly equipped with a fume hood.

For high-quality workpieces, some operators also test the quality of phosphate coatings for corrosion resistance. A typical test involves subjecting a panel that has received a phosphate coating and then a primer to salt spray in a laboratory chamber. The results are then compared with the corrosion resistance demonstrated in the same test using a panel of known quality (several such test panels are commercially available). Some operations also test phosphate coatings for electrical resistance (i.e., the ability to resist galvanic corrosion) with an impedance test.

The key parameters that must be controlled to achieve a quality phosphate coating are concentration, temperature, pH, and dwell time.

Concentration: Within a narrow range, deposition of iron phosphate tends to increase as the concentration of the purchased material in the phosphating solution is increased. That range tops out at 5 percent, beyond which the degree of deposition achieved on the substrate remains essentially unchanged. At concentrations above 5 percent, the process operator is likely to be wasting the phosphating chemicals. A concentration below 3 percent usually will deposit a coating that is too thin to achieve desirable adhesion or corrosion-resistance characteristics. Thus, process operators generally mix phosphating solutions with a 3 to 5 percent concentration of the purchased material. Similarly, specific parameters apply for zinc phosphate. Thus, process operators are strongly advised to follow vendors' recommendations.

Temperature: As with concentration; within a given range deposition increases as the temperature of the phosphating solution is raised. Process operators typically maintain iron phosphate solutions at 120^o to 140^oF, in keeping with vendor recommendations. An exception applies when using low-temperature phosphate materials, for which the phosphating solution is maintained at 90°F. At temperatures above or below the vendor's recommendation, the phosphating reaction might be too fast or too slow, respectively. For instance, if phosphating occurs too quickly, the deposition may be extremely porous. Moreover, phosphating at a high temperature raises energy costs and increases the evaporation of water from the phosphating solution. Similarly, specific parameters apply for zinc phosphate.

Phosphate baths and spray feeds are generally heated by either a burner-and-tube system or by a heat exchanger that incorporates steam. Although the burner-and-tube method has been in use for many years, the more recently installed phosphating equipment tends to incorporate heat exchanger technology, which is more energy efficient and does not generate fumes.

pH: The pH of an iron phosphate bath gives an indication of the acidity. Typical iron phosphating solutions are slightly acidic, in a pH range of 3 to 6 for both immersion and spray applications; zinc phosphating solutions generally are more acidic, in a pH range of 1.8 to 2.4 for immersion and up to 3.0 for spray application (4). Control of pH is critical because the phosphate precipitates out from the solution only when the pH at the substrate/liquid interface is in the correct range. Because the pH range is specific to the particular phosphate formulation, vendor recommendations must be followed exactly.

Dwell Time: For both iron and zinc phosphating, the dwell time required to achieve an adequate conversion coating differs significantly between immersion and spray application. Depending on the concentration of the purchased material, a workpiece immersed in an agitated bath of phosphating solution generally requires a dwell time of 3 to 5 minutes. Agitation brings the fresh chemical in the bath to the substrate/liquid interface, where the electrochemical reactions occur. Thus, agitation is recommended to achieve uniform deposition and to maximize chemical use. In sharp contrast, with spray application the phosphating solution only has to make contact with the workpiece for 60 to 90 seconds. The conversion reaction occurs faster because the spray solution continuously supplies fresh chemicals to the surface of the workpiece.

6.2.3 Best Management Practices

Recommended practices that enhance process efficiency as well as the quality of the phosphate coating include the following:

- To promote proper adhesion for high-durability primer-topcoat systems and to extend the life of immersion baths, process operators should ensure that workpieces are thoroughly rinsed before and after phosphating.
- To maximize the effectiveness of phosphating formulations, operators should confer regularly with vendors and thoroughly test various combinations of acids, accelerators, and surfactants. For many operations, it may be necessary to customize the phosphating formulation to the specifications of the particular coating system.
- To ensure the cost-effective use of chemicals, facility operators should automate the addition of the phosphating formulation to processing tanks. Although capital cost outlays for the installation of flow controllers can be somewhat high, this measure can yield process input savings in the near term.
- To avoid contaminating the phosphated surface with perspiration, skin oils, or general grime, facility operators should require process line workers to wear clean gloves when handling freshly phosphated workpieces. Such contaminants can undermine adhesion of the primer-topcoat system and mar the finish by photographing through.

6.3 Phosphating Methods

6.3.1 Iron Phosphating

For most operations that apply a conversion coating to steel workpieces, iron phosphating is the preferred approach because it is easier to control, less expensive, and generates less sludge than the zinc phosphate method. Iron phosphate yields a conversion coating that generally has less weight than that achieved with zinc phosphating, however, and thus the coating provides less corrosion resistance. Nonetheless, the quality of the deposition is sufficient to meet specifications for the majority of finished workpieces. Although iron phosphate can be used on most steel substrates, it is incompatible with galvanized steel, for which zinc phosphate is recommended.

The iron phosphate process is essentially the pickling of steel in phosphoric acid. The surface of the steel is made up of numerous anode and cathode sites. The acid attacks the steel at the anodes, liberating iron ions into the bath and generating hydrogen gas. An accelerator (i.e., oxidizing agent) is required to oxidize the iron ions and use up the hydrogen at the metal surface. This lowers the acid content, or pH, at the cathodic sites to the point at which iron phosphate naturally precipitates onto the steel surface. This process continues until all cathodic sites (i.e., all surfaces) are coated.

Iron phosphate formulations generally contain a combination of ferrous phosphate, ferric phosphate, and ferric oxide. Process operators typically use solutions that include phosphoric acid, an accelerator, and one or more surfactants (ironically, iron phosphate solutions do not actually contain iron). The surfactants help to wet the substrate, enhancing adhesion of the phosphate coating.

The four types of available iron phosphates are categorized by the accelerator added:

- Chlorate (yielding a gold-blue-gray deposition).
- Molybdate (yielding a blue deposition).
- Sodium metanitrobenzene sulfonate (SNIBS) (yielding a grayish blue deposition).
- Bromate (yielding a blue to bluish gray deposition).

The color of the phosphate coating should be consistent from workpiece to workpiece. A change in color can indicate a problem with the deposition (e.g., the immersion bath is exhausted).

The four types of iron phosphates are sold in both liquid and powder form. The liquid form is generally preferred because it is easier to mix into an immersion bath or spray tank. Powders can be difficult to mix thoroughly into an aqueous form and can generate housekeeping problems. Also, the mix-and-feed of powdered formulations cannot be automated as easily as liquid forms.

Typical deposition weights achieved with iron phosphating range from 25 to 80 mg/ft.[1] Deposition weight depends not only on the control of phosphating process parameters, but also on the type of steel or alloy being treated. Some steels are particularly difficult to-treat. On such substrates, deposition weights may be low regardless of how well the phosphating system is controlled.

6.3.1.1 Process Variations

Wand Application

One method for applying an iron phosphate coating is to subject the workpiece to the phosphating solution with a spray wand. Often the workpiece can be degreased before phosphating and then rinsed afterward using a single wand equipped with an operator feed-source control (see discussion in Chapter 5 on aqueous degreasing). Wand application is primarily used on particularly large workpieces being processed at low volume. In general, this approach does not yield a high-quality surface for application of a primer-topcoat system.

Two-Step Process With Immersion

Another approach involves immersing workpieces into a bath that contains a formulation that combines degreasing and phosphating. The workpiece is then rinsed in the second step in this process. Although economical, this approach tends to leave many contaminants on the substrate, and thus the resulting phosphate coating provides only minimal corrosion resistance. Generally, this approach is used to phosphate workpieces that will not be exposed to corrosive conditions during most of their useful life.

Three-Step Process With Immersion or Spray Washing

The most widely used iron phosphating approach in the general metals industry involves an immersion bath or spray washing step that combines degreasing and iron phosphating followed by two rinse steps. Rinsing can be carried out with municipal tap water, although deionized water is recommended for the second rinse as a way of controlling for residual contaminants. Some operations also add a sealer to the second rise that fills pores in the phosphate coating (see discussion on sealers in Chapter 7). Whereas the three-step process minimizes phosphating costs, the corrosion resistance yielded is not of sufficient quality to meet specifications for higher-value workpieces (e.g., appliances and many other durable goods). (Operations generally do not use a four-step process.)

Processes With Five or More Steps

Operations applying paints and coatings that require high-grade corrosion resistance thoroughly clean and rinse workpieces before and after phosphating. In these systems, phosphating as well as degreasing and rinsing are carried out in dedicated immersion baths or with spray washers.

The five-step approach (i.e., degreaser, tap-water rinse, phosphating, tap-water rinse, and deionized water sealer rinse) often is used for phosphating workpieces that will be put into service outdoors or in generally corrosive environments. Operations coating workpieces with specifications for superior durability (e.g., for large appliances) often use seven or more process steps that include additional rinsing, either by impingement or immersion. Tables 6-3 and 6-4 present examples of two multiple-step process lines for high-quality workpieces. Iron phosphating using such extensive processes yields conversion coatings of quality similar to that achieved with zinc phosphate. Limitations of such approaches concern process costs related to worker training, operation of the system, and floor-space needs.

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[1] As noted in Chapter 5, “degreasing” is used generally in this document to refer to the various liquid/vapor methods used in paints and coatings operations to clean substrates. The author recognizes that some operators use the term degreasing to refer specifically to vapor degreasing.

Table 6-3. Process Line for Pretreatment of Complex Workpieces in Electrocoating Operation (5)

Stage	Description	Process	Time
1	Alkaline cleaner	Spray	60 sec
2	Alkaline cleaner	Immersion	30 sec
3	Water rinse	Spray	30 sec
4	Water rinse	Immersion	30 sec
5	Phosphate	Immersion	60 sec
6	Water rinse	Immersion	30 sec
7	Sealer	Immersion	30 sec
8	Deionized rinse	Immersion	30 sec
8a	Deionized make-up	Spray	Variable
	Drain and flash		5 min

Table 6-4. Process Line for Pretreatment of Simple Workpieces in Electrocoating Operation (5)

Stage	Description	Process	Time
1	Alkaline cleaner	Spray	60 sec
2	Alkaline cleaner	Spray	30 sec
3	Water rinse	Spray	30 sec
4	Water rinse	Spray	30 sec
5	Phosphate	Spray	60 sec
6	Water rinse	Spray	30 sec
7	Sealer	Spray	30 sec
8	Deionized rinse	Spray	30 sec
8a	Deionized make-up	Spray	Variable
	Drain and flash		5 min

6.3.2 Zinc Phosphating

In most operations where the corrosion resistance of finished workpieces must be especially high, conversion coatings are applied using zinc phosphate. This approach is widely used in the automotive industry and in certain sectors of the appliance and electronics industries. Similarly, zinc phosphating is often specified by the armed services, especially for equipment that may be exposed to severe environments. Moreover, many operations using electrocoating or powder coatings, particularly when a one-coat finish will be exposed to the weather, pretreat workpieces with zinc phosphate.

The electrochemical process whereby zinc phosphate deposits on a substrate is similar to the iron phosphating process. As soon as the workpiece is subjected to the acidic solution, metal dissolves at anodic sites.

As in iron phosphating, accelerators (i.e., oxidizers) are an important addition to zinc phosphating solutions. In zinc formulations, accelerators oxidize the iron ions and use up the hydrogen at the metal surface. This lowers the acid content, or pH, at the cathodic sites to the point at which zinc phosphate naturally precipitates onto the steel surface. This process continues until all cathodic sites are coated.

The accelerator performs two basic functions:

- The excess ferrous ions in the solution tend to slow down the phosphating process. The accelerator speeds up the process by oxidizing the excess iron ions, causing them to precipitate out as a ferric phosphate sludge, which extends the life of the bath. (The sludge must later be filtered out of the solution and disposed of as a hazardous waste.)
- By reacting with hydrogen as it is formed at the anodic sites, the accelerator prevents hydrogen gas formation. If an oxidizer were not used, the formation of gas would interfere with the deposition of the phosphate. Thus, addition of an oxidizer (also known as a depolarizer) frequently prevents hydrogen embrittlement of high-strength steel.

Accelerators specifically used with zinc phosphate range in reactivity from mild nitrates to the fairly aggressive chlorates and peroxides. Calcium compounds are particularly favored as accelerators for the low coating weights and compact grain sizes they yield. These typically are used when higher temperature phosphating solutions (i.e., 112^o to 130°F) would otherwise slow conversion kinetics (6). They can also be used in lower temperature baths when accelerators or initiators such as nickel, iron, manganese, and borium are also used.

In general, the crystals that result from zinc phosphating have low porosity and provide a strong base for adhesion of the primer-topcoat system and superior long-term corrosion resistance. Table 6-5 presents the corrosion resistance of various zinc phosphate coatings when subjected to salt spray.

The performance of zinc phosphate formulations increases in the following order:

- Zinc phosphate
- Zinc-calcium phosphate
- Zinc-nickel-fluoride phosphate
- Zinc-nickel-magnesium-fluoride phosphate

Typical conversion coatings deposited on the substrate in zinc phosphating include:

Phosphopyllite	$Zn_2Fe(P0_4)_2.4H_20$
Hopeite	$Zn_3(P0_4)_2.4H_20$
Scholzite	$Ca_2Zn(P0_4)_2.2H_20$
Brushite	$CaHP0_4.2H_20$
Monetite	$CaHP0_4$

Crystal size also is affected by the method used for subjecting the workpiece to the phosphating solution

Table 6-5. Corrosion Resistance of Zinc Phosphate Coatings on Steel and Electrogalvanized Steel (1)

Coating	Salt Spray (DIN 50021 SS)	Constant Temperature Water Condensate (DIN 50017)
Steel		
Untreated	0.1	0.1
Zinc phosphate (unaccelerated)[a]	6	40
Zinc phosphate (nitrate accelerated)[a]	3	24
Zinc phosphate (nitrate accelerated with nickel and polycarbonic acid additions)[a]	250	800
Zinc phosphate (nitrate accelerated + corrosion protection oil)[a]	250	700
Electrogalvanized Steel		
Untreated	1	24
Zinc phosphate (nitrate + nitrite accelerated)[b]	50	150

[a] Approximate coating weight was 25 g/m^2 (2,322 mg/ft^2).
[b] Approximate coating weight was 2 g/m^2 (186 mg/ft^2).
Note: These coatings were intended to provide corrosion protection without the benefit of an organic paint or coating.

and by the thoroughness of the rinsing steps. The particular phosphating method used, however, often depends on the type of workpiece. Typical zinc phosphate coating weights are 100 to 1,000 mg/ft^2 using spray application, whereas coatings can range from 150 to 4,000 mg/ft^2 using immersion tanks (4).

Fewer process variations are applicable to zinc phosphating, given that process operators must thoroughly rinse drag-out and contaminants from workpieces before and after phosphating. Also, each spray or immersion step must be specific to the particular process stage. Thus, for instance, the degreasing and phosphating steps cannot be combined, as they are sometimes in the iron phosphating approach. For operations using zinc phosphating, the process line includes five or more steps in which workpieces are degreased, tap-water rinsed, phosphated, tap-water rinsed, and then rinsed with deionized water.

6.3.3 Wash Primers as an Alternative to Phosphating

Wash primers represent an alternative means of etching a substrate in preparation for receiving a topcoat. These coatings are used primarily on particularly large workpieces that cannot be treated in tanks. The conventional approach for this low-cost pretreatment step, which dates back to the 1940s involves priming the workpiece with a high-VOC coating formulation that slightly etches the substrate; this approach is also known as acid etch. A typical wash primer is a vinyl butyryl organic coating formulated with solvents (e.g., ethyl alcohol and/or isopropyl alcohol), vinyl butyryl resin, phosphoric acid, zinc chromate, water, and an extender pigment.

The high VOC content of conventional wash primers in contrast to other primer coatings represents a significant disadvantage of this approach. The VOC content in typical formulations is about 6.5 lb/gal (780 g/L). Thus, the use of wash primers is an inexpensive but low-quality alternative to phosphating. Typically, facility operators resort to this approach only when a phosphating process line is not an option.

Because most states now require that the VOC content of wash primers not exceed 3.5 lb/gal, facility operators that favor this approach have been experimenting with the less-volatile water-borne wash primers that have become available in recent years. Some of these alternative formulations may meet the military's stringent specifications for quality and pollution prevention (7).

6.4 Waste Minimization and Treatment

6.4.1 Minimization

The key to waste minimization in the phosphating stage of a paints and coatings operation is process efficiency. Applying conversion coatings to workpieces with phosphating chemicals that are appropriate for the particular metal substrate can minimize the generation of heavy metal sludge in immersion baths or from phosphating spray operations. If the color of a deposited coating varies from the coloration associated with particular phosphating formulations, the process operator should check for problems such as exhaustion of the phosphating solution. Both the monitoring of phosphating operations and the replenishing of chemicals can be automated to ensure maximum process efficiency.

In general, some amount of heavy metal sludge is generated in all phosphating, with greater amounts associated with zinc phosphating. In the worst case, the use of phosphating chemicals that are not well suited to a workpiece's metal substrate will fail to deposit a coating and will generate an excess of heavy metal sludge. For example, iron phosphate cannot be used to apply a conversion coating to galvanized steel because the acid will react with the zinc in the substrate but not the iron, resulting in an excess of zinc sludge. Instead, a zinc phosphate formulation should be used to apply a conversion coating on galvanized steel. Similarly, an aluminum substrate will not receive a conversion coating from iron phosphate and will generate an excess of aluminum sludge. Aluminum phosphate should be used to apply conversion coatings to aluminum workpieces. Some nonchromate formulations are used on aluminum workpieces that have low corrosion-resistance requirements (see Section 6.2.1).

Discharges for such operations are regulated under the Clean Water Act at both the federal and state level, and local requirements may apply; also, industry-specific effluent guidelines have been established. Relevant effluent standards established by EPA are specific to metal finishing and electroplating operations (40 CFR Part 413 and Part 433, respectively). These standards stipulate general limitations on heavy metals as shown in Tables 6-6 and 6-7.

6.4.2 Treatment

Contaminated phosphate baths or rinses can be treated in various ways. Raising the pH of an exhausted phosphate bath or of collected spray drainage will precipitate out any heavy metal sludge. The wastewater can then be run through a centrifuge to collect the sludge into a cake, which must be disposed of as a hazardous waste.

A growing trend in phosphate waste treatment is to use ultrafiltration to maintain clean rinses. Ultrafiltration pumps the rinse water through membranes and allows the return of concentrates to the phosphate bath and purified water to the rinse tank. This additional step maximizes water use and reduces the amount of wastewater discharged to local treatment works.

Table 6-6. Pretreatment Standards for Existing Sources That Electroplate Common Metals and Discharge 38,000 Liters or More of Wastewater per Day

Pollutant or Pollutant Property	Maximum for Any 1 Day (mg/L)	Average of Daily Values for 4 Consecutive Monitoring Days Shall Not Exceed (mg/L)
Cyanide, total	1.9	1.0
Copper	4.5	2.7
Nickel	4.1	2.6
Chromium	7.0	4.0
Zinc	4.2	2.6
Lead	0.6	0.4
Cadmium	1.2	0.7
Total metals	10.5	6.8

Source: Electroplating of Common Metals, 40 CFR Section 413.14.

Table 6-7. Pretreatment Standards for Existing Sources Involved in Metal Finishing Operations (for All Facilities Except Circuit Board Manufacturers)

Pollutant or Pollutant Property	Maximum for Any 1 Day (mg/L)	Monthly Average Shall Not Exceed (mg/L)
Cadmium, total	0.69	0.26
Chromium, total	2.77	1.71
Copper, total	3.38	2.07
Lead, total	0.69	0.43
Nickel, total	3.98	2.38
Silver, total	0.43	0.24
Zinc, total	2.61	1.48
Cyanide, total	1.20	0.65
Total toxic organics	2.13	

Source: Metal Finishing Point Source Category, 40 CFR Section 433.15.

6.5 Additional Considerations Related to Phosphating

6.5.1 Choosing a Phosphate Formulation and Qualifying the Phosphate Coating

Paints and coatings facility operators typically confer with chemical vendors in the selection of a phosphate formulation. Indeed, one vendor may be able to offer a better formulation than another vendor, especially if the performance requirements are unique.

The choice of formulation can be significant in terms of achieving optimum coating properties. It is especially prudent for the operator to discuss special requirements with a chemical vendor, particularly if the finished workpiece will be subjected to aggressive environments. In some situations, laboratory tests may need to be conducted to verify that the selected coating will be able to provide the required finish. In general, choosing a formulation on the basis of price is inadvisable.

6.5.2 Degreasing Before Phosphating

Degreasing formulations are varied and must be selected according to the types of contaminants that need to be removed from workpieces (8). The most common types are alkaline and acid cleaners. (For a more extensive discussion of degreasing, see Chapter 5.)

Degreasers should have the following characteristics (9):

- Sufficient detergency to remove a wide variety of soils.
- Capability to be easily rinsed, so that residues do not contaminate the phosphating stage.
- Sufficiently mild that components of the formulation do not attack zinc and aluminum, which may be processed together with steel in the workpieces.

Also, degreasers used in spray cleaning systems must have controlled foaming characteristics.

A rinsing step after degreasing can be used to accomplish the following:

- Remove trace contaminants from the workpiece.

- Minimize the likelihood of alkaline salts and grime contaminating the phosphate bath.
- Prevent the alkaline salts from raising the pH of the phosphate bath.

The cleanliness of the substrate as the workpiece enters the phosphating step or as it leaves the final rinse tank should pass the water break-free or the towel-wipe test. In the water break-free test, a squirt bottle is used to pour deionized water over a cleaned substrate. The water should run off in a sheet rather than bead up. While the test may demonstrate that oils and greases have been removed from the workpiece, it will not confirm that the surfactants from the degreaser have also been removed. To do this, one needs to rinse the part with a small quantity of deionized water and then determine the pH of the water. This can easily be done using pH papers.

To determine that metal fines, smut, and other contaminants have been removed, a clean paper towel should be wiped across the wet surface of the workpiece. Whereas the test may not always result in a perfectly clean towel, relative changes in cleanliness can be assessed (8).

If the degreasing formulation is properly selected for an immersion process, contaminants from workpieces will either sink to the bottom of the tank or float to the top (i.e., the oils will float rather than emulsify). The line operator can then easily filter out the insoluble sludges or separate off the oils. Sludge material can be dried and then disposed of as hazardous waste, whereas the oils can be sent off site for fuels blending.

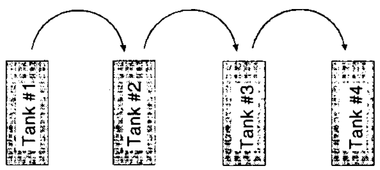
6.5.3 Design of an Immersion Tank System

Rinsing by immersion is ideal for situations in which:

- The production flow through the process is relatively slow (i.e., less than 2 ft/min on a continuous basis).
- Production is intermittent.
- The configuration of the workpieces is such that a spray washer could not thoroughly wet all parts (e.g., boxed and channel sections).
- Available floor space would not accommodate a spray washer system.
- Parts to be processed can be placed in baskets more easily or cost effectively than if hung on a conveyor line.
- Workpieces are so large that a spray washing system would be prohibitively expensive.

A facility operator considering the installation of an immersion system should consult with a specialized contractor about design and layout.

Figure 6-2 illustrates two typical immersion system layouts: Figure 6-2(a) shows the more common layout for a typical batch operation; Figure 6-2(b) shows a less-common layout that would rely on a conveyor to carry workpieces in and out of the tanks in a continuous process. (For a detailed discussion of rinsing operations, see Chapter 7.)



(a) Immersion tanks laid out for batch operation.

(b) Immersion tanks laid out for continuous conveyorized operation.

Figure 6-2. **Immersion rinse system schematic.**

6.54 Design of a Spray Washer System

A spray rinse system is often recommended for a paints and coatings operation that has a conveyor line with a speed greater than 2 ft/min.

Advantages of the spray washer approach include:

- Increased impingement afforded by high-pressure nozzles, providing more efficient cleaning and uniform phosphate coating deposition.
- Increased production, given the ability to effectively pretreat thousands of tons per year of metal workpieces on a continuous basis.

Limitations of the spray washer approach include:

- Inability to apply the phosphate coating uniformly on workpieces with complex geometries (e.g., with recesses and crevices), particularly on spray washer “shadow” areas.
- Inability to provide the same wash effectiveness to parts, particularly if some are very large and others very small (i.e., smaller parts will be farther from the spray nozzle and thus subjected to lower impingement pressure).
- Greater floor-space requirements, particularly for fast-moving conveyors.
- Greater energy losses due to the high evaporation rate of hot water.
- Higher equipment costs (e.g., for pumps, motors).

- Higher maintenance costs due to the need for frequent cleaning and replacement of nozzles, as well as the need to lubricate the conveyor system, which is continuously subjected to a moist environment.

A facility operator considering the installation of a spray washer line would be well advised to consult with a specialized contracting company. In general, when planning for a spray washer, the facility operator needs to consider how the layout will affect process flow. The spray washer system must be designed so that workpieces can easily pass through the pretreatment process, allowing adequate time for the solutions to drain between each tank.

A spray washer system cannot be properly designed unless the conveyor line speed and the part sizes are known. The dimensions of the spray tunnel must be based on the silhouette of the maximum part size. The spray nozzles inside the tunnel must be located on risers so that they are only a few inches away from the largest part.

When possible, a system should be designed so that spray rinses precede every process tank. Although the rinses are at low pressures, they enhance pretreatment by preventing the contamination of tanks with chemicals from a preceding tank. Operation of such spray washers is relatively inexpensive because low volumes of water are used.

Given the vast number of workpieces and parts of varying size that can pass through a spray system each day for certain operations, nozzles can often be misdirected. Thus, a maintenance engineer should routinely check to see that spray nozzles are pointing in the correct direction.

A design feature often overlooked regards conveyors that pass workpieces through the tunnel, dry-off oven, and spray booths, as shown in Figure 6-3. The advantage of such designs is that line workers are only needed for hanging and offloading workpieces.

6.5.5 Process and Quality Control Measures

Specification TT-490-D (7) is the military specification that covers cleaning and pretreating ferrous surfaces for organic coatings. This document is useful even for operations not performing work for the military because it provides excellent guidelines for process and quality control (see also Reference 10).

Beyond following general guidelines, it is imperative that facility operators conduct process control tests recommended by the vendor on a regular basis. These include tests relating to pH, concentration, total acid, temperature, and dwell time. Also, operators should be careful that processing tanks do not become over contaminated because the effectiveness of pretreatment can be undermined.

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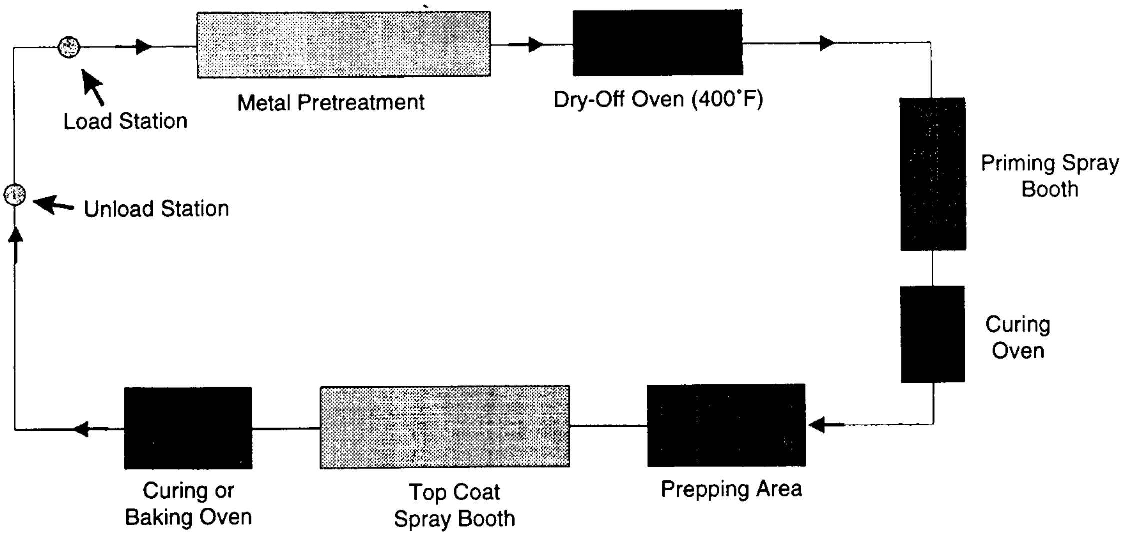

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Chapter 7
Rinsing Process Efficiency and Alternatives to Chromate-Based Sealers

7.1 Introduction

7.1.1 Pollution Prevention Considerations

Thorough rinsing is the most important factor in the paints and coatings process for ensuring that workpieces receive a high-quality finish. Without rinsing away residual surfactants, excess alkalinity, or unreacted acids, for example, a finish can degrade prematurely, if not fail catastrophically. Sealing the phosphate coating can be equally important for ensuring the quality of the finished piece.

Pollution prevention is a critical consideration for these process steps because many operations generate high volumes of wastewater when rinsing and sealing workpieces. Additionally, the chromate-based formulations traditionally used in sealing rinse baths generate toxic residues, some of which must be handled as hazardous waste.

Often, however, these wastes can be minimized through process modifications that can yield overall efficiencies and cost savings. The volumes of rinse wastewater generated, for instance, can be dramatically reduced at the same time that rinsing efficiency is enhanced by using a multiple-bath method called counter-flow rinsing. Similarly, the generation of hazardous chromate residuals can be controlled, and in some cases eliminated, by switching to nonchromate formulations. While nontoxic sealers are not considered as effective as chromate-based formulations in all operations, many processes may realize cost and process benefits from using these alternatives.

These pollution prevention approaches are discussed in this chapter in the context of best management practices associated with the rinsing and sealing process steps. In a general sense, any process operated efficiently controls the unnecessary generation of pollution to the degree that the operation minimizes overall waste and the number of workpieces that must be rejected and disposed of or reprocessed. Indeed, the pretreatment process stages of rinsing and sealing are particularly important in a right-first-time approach to applying paints and coatings. By ensuring thorough rinsing and sealing, an operator can avoid corrective measures, which tend to be both chemically intensive and expensive.

7.1.2 Decision-Making Criteria

Decision-making criteria relevant to rinsing process efficiency and alternatives to chromate-based sealers, as addressed in this chapter, are highlighted in Table 7-1.

7.2 Rinsing

The primary purpose of the rinsing step in the paints and coatings process is to clean contaminants from the workpiece before it moves on to the next stage in the sequence. Depending on where rinsing takes place in the overall process, contaminants can include dirt, sanding dust, metal fines, or any other particulates as well as chemicals, solvents, or residues that may adhere to the workpiece. Thorough rinsing can both enhance the ultimate quality and durability of the finished piece and minimize contamination of downstream steps in the process flow.

The number of rinsing steps in a process, as well as the number of baths in a given step, primarily depends on the quality requirements for the finished workpiece. Indeed, rinsing might be left out entirely from the paints and coatings process for a particularly low-value piece; however, best management practice would argue in favor of a minimum of one rinsing stage to maximize process efficiency by controlling drag-out from one bath to another. The most effective method of rinsing is the counter-flow approach, which relies on multiple baths to provide thorough rinsing of the workpiece while minimizing the volume of rinse water used (see Section 7.2.2).

The typical process flow for a high-value paints and coatings operation includes a step for rinsing the cleaning-formulation residues from the workpiece after degreasing and then rinsing the piece again after phosphating to remove unreacted acids. These two rinsing steps are described below following a brief discussion of the basics of the rinsing process. This section also includes a discussion of wastewater minimization using the counter-flow rinsing approach.

Table 7-1. Decision-Making Criteria Regarding Rinsing Processes

issue	Considerations
Does the pretreatment system include degreasing and phosphating as a single stage?	· If yes, then rinsing before phosphating is not a consideration. · Regardless of whether these stages are separate, at least one rinse with municipal tap water should follow phosphating. · Addition of a sealing rinse in a static tank should also be considered.
Does the pretreatment system include degreasing and phosphating as separate stages?	· if yes, then rinsing with tap water after degreasing should be included.
Will the paint finish on workpieces be solely for appearance (i.e., corrosion and other physical properties have little significance)?	· Many low-value workpieces (i.e., household products) for price-sensitive markets are in this category. Manufacturers often cannot justify improvements in the coatings process on a value-added basis. · When corrosion-resistance requirements are low, it may be cost effective to conduct degreasing and phosphating in one step, followed by at least one municipal tap water rinse. · Addition of a sealing rinse in a static tank should also be considered.
Will the finished workpieces be required to have only low corrosion resistance (i.e., be able to withstand between 96 and 168 hours of salt fog exposure per ASTM B-117 [see Reference 1])?	· Most finished metal products are in this category because they might be subjected to a moderate degree of outdoor exposure (i.e., not particularly corrosive elements). · It may be cost effective to conduct degreasing and phosphating in one step. · Consideration should be given to separate stages, with at least one tap water rinse between the two stages. · If separate stages are used, a second post-degreasing rinse with deionized water should be considered for extending the useful life of the phosphating bath. The second bath is particularly important if the process line does not allow time for sufficient draining before phosphating. · A sealing rinse should be considered mandatory. · If it can be shown that the primer-topcoat system will provide the required corrosion resistance, consideration should be given to using a nonchromate sealer. · Rinse drainage should be collected and recycled. · If two or more rinse tanks follow degreasing or phosphating, consideration should be given to using a counter-flow system. · If one or more of these rinses use deionized water, consideration should be given to installing automatic flow controllers, which monitor the concentration of chemicals in the rinse tank. · If degreased and phosphated workpieces will be stored outdoors for several days prior to application of a primer-topcoat system, consideration should be given to using a chromate sealer for enhanced corrosion resistance. Expectations are that nonchromate sealers eventually will be proven fully equivalent to conventional sealers in corrosive environments.
Will the primed workpieces be required to have moderate corrosion resistance (i.e., be able to withstand between 168 and 500 hours of salt fog exposure per ASTM B-117 [see Reference 1])?	· This might apply to products that are subjected to outdoor exposure in all types of weather, to marine environments, or to chemical vapors. · Same considerations as for low-corrosion resistance requirements above, although additional emphasis should be placed on multiple rinse steps.
Will the finished workpieces be required to have superior corrosion resistance (i.e., be able to withstand at least 500 hours of salt fog exposure)?	· This usually applies to workpieces in automotive manufacturing. Electrocoating is used on most automotive parts, a process that cannot tolerate any drag-in from pretreatment steps. · Following degreasing, the workpiece must undergo at least one tap water rinse followed by a deionized water rinse. · At least two tap water post-phosphating rinses must be included, followed by rinsing with deionized water. · A sealing rinse should be considered mandatory. · If it can be shown that the primer-topcoat system will provide the required corrosion resistance, consideration should be given to using a nonchromate sealer. · Rinse drainage should be collected and recycled. · If two or more rinse tanks follow degreasing or phosphating, consideration should be given to using a counter-flow system. · If one or more of these rinses use deionized water, consideration should be given to installing automatic flow controllers, which monitor the concentration of chemicals in the rinse tank. · If degreased and phosphated workpieces will be stored outdoors for several days prior to application of a primer-topcoat system, consideration should be given to using a chromate sealer for enhanced corrosion resistance.
is the useful life of the phosphate bath shorter than what is projected in vendor literature?	· Additional emphasis should be placed on rinsing after degreasing. · Also, rinse drainage should be collected and recycled.

7.2.1 Rinsing Basics and Best Management Practices

By monitoring and controlling basic aspects of the rinse stages of the paints and coatings process, an operator can enhance overall efficiency, while minimizing the amount of wastewater discharged by extending the useful life of rinse baths. The most important of these considerations are water quality, immersion time, rinse temperature, agitation or impingement, workpiece geometry, system loading, and rinse water dumping.

Water quality. Most operations that include a rinse stage use municipal tap water, which typically is slightly acidic (i.e., pH of 5.0 to 5.3) and with low resistivity (i.e., about 5 megohm/cm). Although the quality of tap water can vary depending on its source, it generally includes any number of impurities, such as ions of sodium, magnesium, iron, calcium, potassium, chlorine, sulfates, carbonates, and nitrates. As tap water evaporates from a rinsed workpiece, ions are left on the surface (i.e., only the volatile molecules will evaporate). Because the ions can conduct an electrolytic current (see Chapter 3) they can cause corrosion to occur, even after a primer or topcoat has been applied to the workpiece.

For many workpieces, this corrosion potential is not a paramount issue. For high-value pieces, however, most operators enhance long-term durability by using deionized water for final rinsing (e.g., the second and third step in multiple rinse stages), which removes corrosive residues from workpiece surfaces. Tap water can be deionized using a sophisticated ion-stripping technology (e.g., ion exchange resins). Deionized water typically has a relatively high resistivity (i.e., about 18.3 megohm/cm) (2) and a neutral pH (i.e., 7). The purer the rinse water, the longer its useful life. Chemical vendors usually are willing to provide log sheets to assist the operator in determining the degree of contamination that rinse water can withstand. Some operators also rely on instrumentation for monitoring the pH and conductivity of rinse water as a way of gauging its useful life.

Immersion time. To ensure removal of as much contaminant as possible, the workpiece must remain in the rinse bath long enough for all residues to be removed. Allowing a steel piece to remain in the bath for an excessive period of time, however, can encourage flash rusting (i.e., the formation of ferrous hydroxide [rust] on the surface of the steel). Steel is particularly prone to flash rusting after it has undergone degreasing and before it has received a phosphate coating. Because at this point the surface has been cleared of protective oils, flash rusting can easily occur if the steel remains wet for more than a few seconds.

Rinse *temperature.* Rinsing is typically carried out using water at ambient temperature. Heated rinse water, however, can enhance the capacity of the rinse stage to remove certain types of contaminants from the workpiece. More specifically, for rinsing after phosphating, the use of heated water can expedite drying of the phosphated piece.

Agitation or impingement (spray washing). Efficient removal of contaminants from a workpiece can be achieved by subjecting the piece to agitation or impingement during the rinsing step. For systems in which the workpiece is immersed in the rinse bath, agitation is typically provided by air sparging, using compressed air at low pressure (i.e., 10 to 20 psi). In contrast, the impingement approach involves spray washing the workpiece with 100 to 150 psi of pressure while the piece is suspended above the rinse bath. For a spray washing system to be effective, the nozzles must be correctly configured and directed to wet all surfaces of the workpiece. Nozzles should be checked and maintained regularly. Spray washing often is used either in addition to immersion rinsing for high-value workpieces or in place of immersion rinsing when floor space is limited.

Workpiece geometry Large workpieces and pieces with complex geometries (e.g., with channels and box sections that are difficult to reach with rinse water) can make efficient rinsing difficult. For such pieces, racking or suspension from conveyors may be necessary to allow for thorough drainage before and after the rinse step. For pieces with particularly complex geometries, drilling small drainage holes in workpiece sections might be necessary. In immersion operations, most rinse water drainage can be captured by allowing the workpiece to remain suspended over the rinse tank for a few minutes. Also, many conveyor systems include a sloped metal tray that collects drainage and channels it back to the rinse tank.

System loading. An operator can boost production by tightly loading a conveyor or rack system that moves workpieces through the rinse stage. Excessive loading of rinse baths relative to the dilution ratio, however, can undermine the efficiency of this stage of the process, and ultimately the quality of the finished piece. Thus, the system loading rate needs to be balanced against the performance requirements of the workpiece.

Rinse water dumping. Generally a rinse bath is kept at equilibrium by discharging effluent as the tank is infused with fresh makeup water. The rinsing process can be optimized, however, by periodically dumping the entire rinse bath into the wastewater treatment system. The frequency of dumping should be determined based on such factors as rinse tank volume and workpiece size. Titrations (i.e., tests for determining the concentration of contaminants in the rinse water) performed on site and laboratory analysis can provide qualitative data for scheduling the routine dumping of a system's rinse water. Pretreatment chemical vendors can supply titration equipment and training as well as advice about testing frequency.

7.2.1.1 Rinsing Following Degreasing

Before receiving a phosphate coating, a metal workpiece should be thoroughly rinsed to remove any surfactant residues from the degreasing step. While the surfactants in degreasing formulations are essential for removing contaminants from a workpiece, their typically low surface tensions make them extremely difficult to remove without thorough rinsing. Surfactants and other contaminants that remain on the surface of the workpiece following degreasing can undermine the integrity of the phosphate deposition and ultimately the quality of the finished piece.

An additional reason for including a rinsing step at this stage of the process is to minimize the amount of drag-in from the high-alkaline degreasing bath (i.e., typically with a pH greater than 10) to the near-neutral phosphating bath (i.e., a pH of 5 to 6, depending on the composition of the bath). Drag-in from a degreasing bath or from an exhausted post-degreasing rinse will gradually neutralize the phosphating bath until little or no phosphate deposits on the workpiece. Even before a phosphating bath reaches this point, it should be dumped. Thus, eliminating this rinsing step can dramatically shorten the useful life of the phosphating bath.

Although many operations rinse their degreased workpieces in a single bath before the pieces receive a phosphate coating, companies that produce high-value finished pieces typically include a multiple-bath rinse step following degreasing. For instance, companies that apply paints and coatings to automotive parts, large appliances, exterior-use coils, and office furniture, as well as in many electrocoating operations, rinse workpieces after degreasing especially thoroughly to meet demanding durability and performance specifications.

Figure 7-1 presents a schematic of a post-degreasing rinse stage that includes two baths-the first using municipal tap water and the second using deionized water-and an optional spray rinse. This type of rinsing system would be used in an operation finishing workpieces with particularly high-performance requirements.

In contrast, many operations can meet less-demanding requirements for coatings without including a phosphating step following degreasing or alternatively by using a single rinse bath. The tradeoff in terms of the finished piece yielded by an abbreviated process such as this is that the coating can fail catastrophically. Because many coatings are sensitive to alkalinity, they can break down to form soaps by means of a saponification reaction. When this occurs, large areas of the coating may flake, or spall, from the surface.

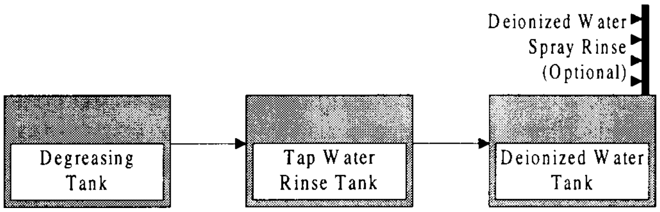


Figure 7-1. Schematic of three-step post-degreasing rinse stage.

Operations that include multiple-bath rinse stages often use municipal tap water in the first bath for removing the highest concentrations of contaminants, ending the rinse stage with a deionized water bath that removes tap water impurities left on the workpiece surface. Because tap water is generally inexpensive and readily available at high flow rates, operators try to use it for rinsing where appropriate. Although deionized water is not particularly expensive, it must be generated on site and flow rates tend to be limited. Also, the ion exchange resins typically used to deionize water eventually become exhausted and must be regenerated or replaced at additional cost. By using the counter-flow rinsing approach, operators can minimize the volume of deionized water required to perform superior rinsing (see Section 7.2.2).

Operators who apply a deposition coating using *zinc phosphating* can enhance process efficiency by adding a low concentration of a titanium salt to the rinse stage immediately preceding the phosphating tank. Titanium salt acts as an activator in initiating nucleation of the zinc phosphate crystals. For this rinsing step, chemical vendors strongly recommend the use of deionized rather than municipal tap water.

7.2.1.2 Rinsing Following Phosphating

For certain types of operations, a second rinse stage is included to remove drag-out of unreacted acids, sludge deposits, corrosive salts, and other contaminants that remain on the workpiece following phosphating. To achieve a quality finish, the primer and topcoat must be applied to a workpiece that is as free as possible of contaminants. Without thorough rinsing at the end of the pretreatment process, the ability of the organic coating system to provide the designed-in corrosion resistance and other physical properties can be undermined. Moreover, contaminants that remain on the workpiece after phosphating can “photograph” through or stain the topcoat, marring the finished piece.

Alternatively, some operators rinse workpieces after the phosphating step primarily to arrest or slow the phosphating process at a certain point. In processes in which the thickness of the conversion coating is a critical parameter, operators typically include a stage for rapid and thorough rinsing of the workpiece.

In contrast to the detrimental effect that surface alkalinity can have on a primer-topcoat system, a slightly acidic surface enhances initial adhesion of the primer as well as long-term corrosion resistance. Thus, for many operations, municipal tap water can be used for rinsing at this stage. Although tap water has a slightly higher pH than the phosphating chemicals, the rinse does not need to raise the pH of the workpiece surface to neutral (i.e., pH 7.0). Most municipal water is unsuitable for use directly from the tap for operations coating workpieces of especially high value. This is due to the presence of impurities (e.g., soluble and insoluble metal salts). Often, however, tap water is used for the initial step in a multiple-bath rinse stage. For high-value operations, deionized water is preferred for all subsequent rinse baths.

Whereas a single rinse bath following degreasing may be sufficient for some operations, the use of multiple baths following phosphating is recommended for most workpieces. In general, a single post-phosphating rinse would leave considerable residue on the workpiece as it passes through the dry-off oven and enters the primer-topcoat application stage. Thus, at a minimum, a second rinse stage, preferably one that also functions as the sealing rinse (see Section 7.3), should be included for most paints and coatings processes. As with the degreasing rinse, the counter-flow rinsing approach is an effective method at this stage for maximizing process efficiency (see Section 7.2.2). Operations finishing high-value workpieces typically include a system of at least three post-phosphating rinses, two of which bathe the piece in deionized water, followed by spray or mist rinsing with deionized water.

7.2.2 Counter-Flow Rinsing

As well as being an effective method for thoroughly washing contaminants from workpieces after degreasing or phosphating, counter-flow rinsing is a particularly effective method for minimizing water usage. Nonetheless, few managers of paints and coatings operations have a sufficient understanding of this rinsing method as a process control strategy.

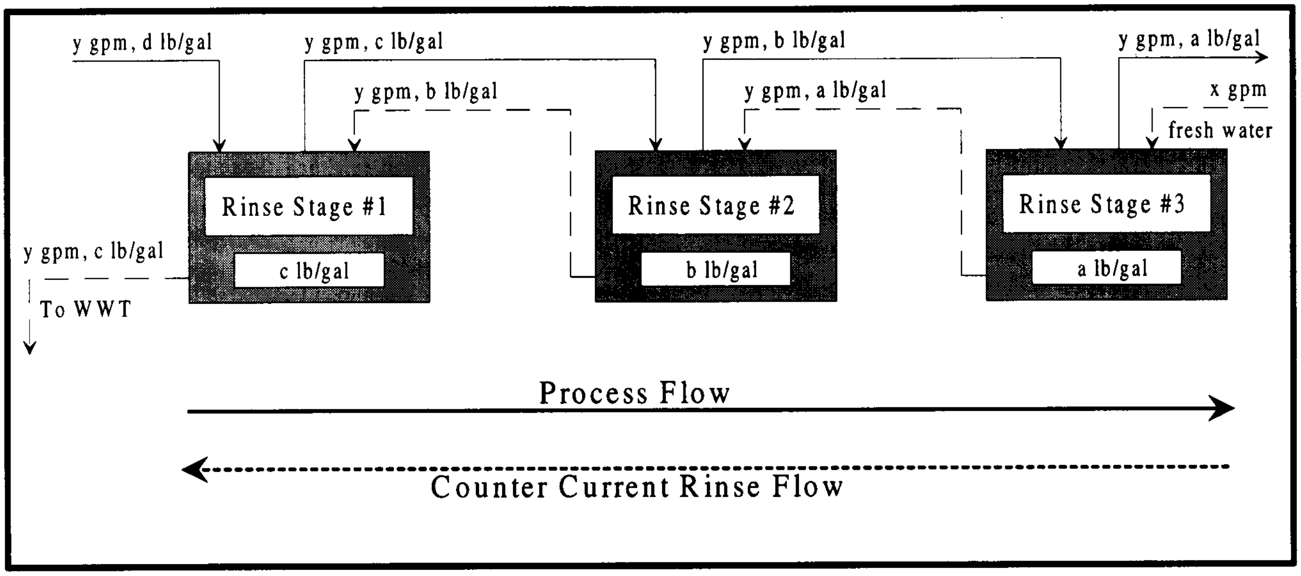
Fundamentally, a counter-flow rinsing system is a sequence of baths (i.e., two or more) in which replenished rinse water moves in the opposite direction of the process flow. Thus, the workpiece progresses from dirtier to cleaner rinse water (Figure 7-2). The system maximizes water use by replenishing the rinse at the final bath in the sequence; overflow from each bath in the sequence in turn replenishes rinse water in the preceding bath. Rinse water effluent is ultimately released to the wastewater treatment system as overflow from the first (dirtiest) bath in the sequence. The basic concept behind counter-flow rinsing is that the makeup water in the first bath in a rinsing sequence does not need to be as clean as that in the last.

The key to an effective rinse system based on this approach is maintaining the dilution ratio from the first to the last bath in the counter-flow sequence. The dilution ratio is primarily a factor of the system's rinse water flow rate versus the workpiece drag-in rate. For instance, if the degreasing tank has a chemical concentration of 1 lb/gal, then the workpiece will drag 1 lb/gal of chemical into the first rinse tank. If that rinse tank holds 99 gallons of uncontaminated water, the chemical concentration of the tank with the 1 gallon of drag-in will be 1 pound of chemical per 100 gallons of water; thus, the chemical concentration will be 0.01 lb/gal and the dilution ratio will be 100:1.

Related considerations, however, include the concentration of contaminant in the makeup water replenishing a bath and the contaminant concentration in the bath itself. Equations for calculating the rinse water flow rate and number of rinse baths required to achieve a specified dilution ratio are provided and explained in Appendix B.

Controlling a system's dilution ratio allows the operator to take advantage of one of the principal benefits of counter-flow rinsing: reducing the overall volume of water required for cleaning a workpiece by adding baths. A single rinse bath quickly loses its effectiveness unless relatively large volumes of water are added to maintain the dilution ratio. Figures 7-2 and 7-3 illustrate water usage needs relative to time for maintaining a dilution ratio in a one-step rinse system of 1,000:1 gallons of rinse water to contaminant. Based on this illustration, a one-step rinse for a workpiece with a drag-in rate of 1 gal/min would consume large amounts of water. To be effective, the process would require either a large-volume tank or a small tank with rinse water changed (i.e., dumped) frequently.

By comparing gallon-per-minute flow rates required to clean a workpiece with a 1 gal/min contaminant drag-in rate, Table 7-2 indicates the reduction in water use that can be realized by increasing the number of baths in a counter-flow rinsing system. Thus, Table 7-2 shows that when a process's dilution ratio is 100:1, adding a second bath reduces the flow rate requirement from 99 to 9.5 gal/min. The operator of this system would reduce the water requirement to 2.3 gal/min by adding a fifth rinse bath. Note that for a dilution ratio of 20,000:1 (required for some particularly high-value workpieces), the flow rate specified for a five-bath system is 7.0 gal/min, which is only about three times the rate for a 100:1 dilution rate. Table 7-3 provides another perspective on the process efficiency advantages of counter-flow rinsing by presenting water flow rates in terms of percentage reductions between additional baths. For example (based on the data in Table 7-2), with a dilution ratio of 100:1 for a workpiece with a 1 gal/min drag-in, the flow rate reduc-



a = concentration of chemical in Bath #3 (lb/gal)
b = concentration of chemical in Bath #2 (lb/gal)
c = concentration of chemical in Bath #l (lb/gal)
d = concentration of chemical in process bath (lb/gal)
x = flow rate of counter-flow rinse (gal/min)
y = flow rate of drag-in (gal/min)

Figure 7-2. Schematic of counter-flow rinsing.

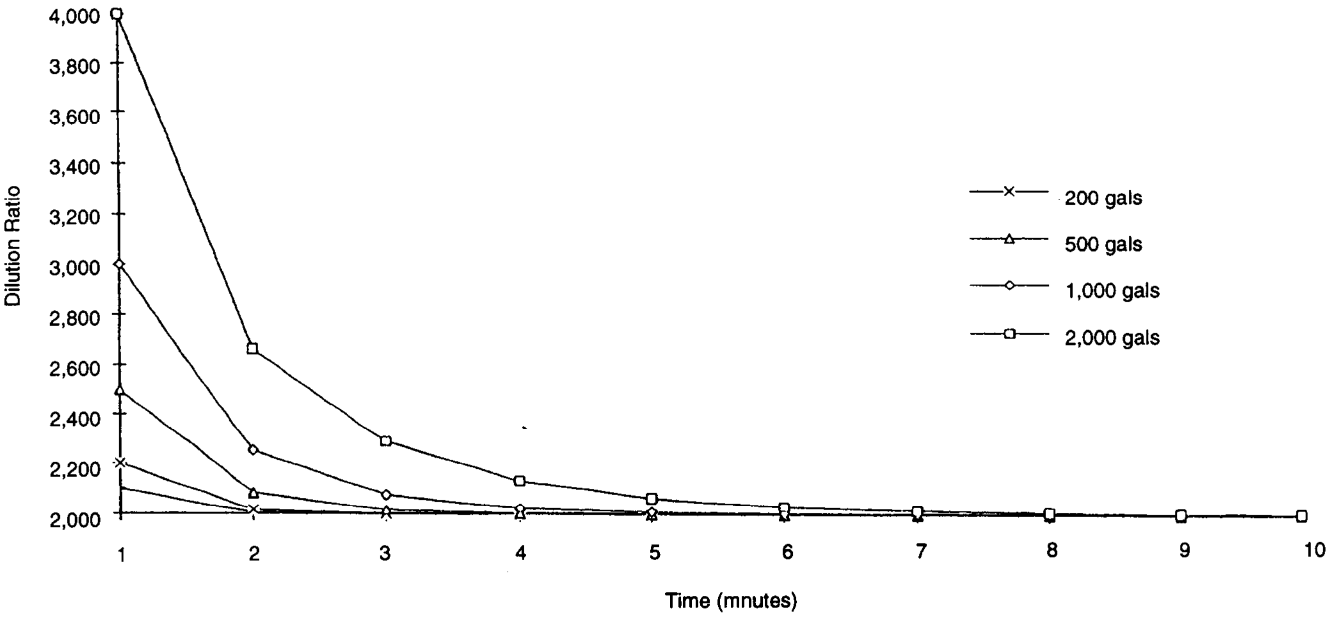


Figure 7-3. Dilution ratio as a function of time for different tank sizes (based on a process as illustrated in Figure 7-2 and assuming a 1,000 gallon process tank and a 1 gal/min drag-out to the first rinse tank).

tion that can be achieved by adding a second rinse bath is 90.4 percent (as shown in Equation 7-1); addition of a third bath would reduce the flow rate to 95.7 (as shown in Equation 7-2).

$$\% \text{ Reduction} = \frac{(99-9.5)}{99} * 100 = \frac{89.5 * 100}{99} = 90.4\% \qquad \text{(Eq. 7-1)}$$

$$\% \text{ Reduction} = \frac{(99-4.3)}{99} * 100 = 95.7\% \qquad \text{(Eq. 7-2)}$$

Comparison of Figures 7-4 and 7-5 illustrates the point that significant reduction in water usage can be realized with the counter-flow, multiple-bath rinsing method.

Table 7-2. Counter-Flow Rates for Workpieces With a 1 gal/min Drag-In

Dilution Ratio	Flow Rates (gal/min) Stage 1 Rinse	Stage 2 Rinse	Stage 3 Rinse	Stage 4 Rinse	Stage 5 Rinse
100:1	99	9.5	4.3	2.9	2.3
1,000:1	999	31.1	9.6	5.3	3.7
2,000:1	1,999	44.2	12.2	6.4	4.3
5,000:1	4,999	70.2	16.7	8.1	5.3
10,000:1	9,999	99.5	21.2	9.7	6.0
20,000:1	19,999	140.9	26.8	11.6	7.0

Table 7-3. Total Percentage Reduction in Flow Rate From One Rinse Tank to the Next for Workpieces With a 1 gal/min Drag-In

Dilution Ratio	Flow-Rate Reduction (%) Stage 1 > 2	Stage 2 > 3	Stage 3 > 4	Stage 4 > 5
100:1	90	95.7	97.1	97.7
1,000:1	97	99.0	99.5	99.6
2,000:1	98	99.4	99.7	99.8
5,000:1	99	99.7	99.8	99.9
10,000:1	99	99.8	99.9	99.9
20,000:1	99	99.9	99.9	100.0

Table 7-4. Counter-Flow Rates for Workpieces With a 2 gal/min Drag-In

Dilution Ratio	Flow Rates (gal/min) Stage 1 Rinse	Stage 2 Rinse	Stage 3 Rinse	Stage 4 Rinse	Stage 5 Rinse
100:1	198	19	8.5	5.7	4.5
1,000:1	1,999	62.2	19.3	10.6	7.5
2,000:1	3,999	88.4	24.5	12.8	8.7
5,000:1	9,999	140.4	33.5	16.2	10.5
10,000:1	19,999	199	42.4	19.5	12.2
20,000:1	39,999	281.8	53.6	23.3	14.1

Table 7-5. Counter-Flow Rates for Workpieces With a 0.5 gal/min Drag-In

Dilution Ratio	Flow Rates (gal/min) Stage 1 Rinse	Stage 2 Rinse	Stage 3 Rinse	Stage 4 Rinse	Stage 5 Rinse
100:1	50	4.8	2.2	1.5	1.2
1,000:1	500	15.6	4.8	2.7	1.9
2,000:1	1,000	22.1	6.1	3.2	2.2
5,000:1	2,500	35.1	8.4	4.1	2.7
10,000:1	5,000	49.8	10.6	4.9	3.0
20,000:1	10,000	70.5	13.4	5.8	3.5

Flow rate requirements in a counter-flow system are influenced, however, by the rate of drag-in for the workpiece. As indicated by comparing Table 7-2 with Table 7-4, if the drag-in rate for a workpiece increases from 1 to 2 gal/min, the counter-flow rate requirement will increase by a factor of 2. Conversely, as indicated by comparing Table 7-2 with Table 7-5, if the drag-in drops to 0.05 gal/min, the flow rate needs will be cut in half.

The flow rate between tanks in a counter-flow system should be set and monitored using automatic flow controllers. This ensures that the rinsing system runs at optimal efficiency and avoids the possibility that the rate will be altered with each work shift.

7.3 Sealing

Some operations subject workpieces to a final rinse bath after phosphating to harden the deposited phosphate coating, providing enhanced long-term corrosion resistance. This process step is included in operations for a wide range of industries, most of which apply coatings to high-value workpieces. Typically, workpieces are sealed using a rinse of deionized water mixed with a small concentration of chromate or nonchromate additive (Figure 7-6). Information on specific formulations is generally available from pretreatment chemical suppliers. Pollution prevention considerations regarding the use of chromate rinses are addressed below following a discussion of the basics of the sealing process.

7.3.1 Sealing Basics

With chromate-based sealing rinses, chemicals in the additive seek out areas of the coating (i.e., porosities and voids) where the phosphate failed to convert the base metal. The chemicals then react with the exposed substrate, in much the same way as the phosphating process itself, to form a corrosion-resistant film. Nonchromate sealers (e.g., polymer sealers) also form a protective film over exposed areas of the substrate, although not through a chemical reaction with the base metal.

The protective film yielded by a sealing rinse provides a barrier between the exposed base metal and the environment. Shielding the substrate from atmospheric moisture and oxygen prevents electrolytic corrosion from occurring. The superior corrosion resistance afforded by chromate sealers is particularly important for operations that store unprimed steel workpieces outdoors for several days or more before applying a coating system.

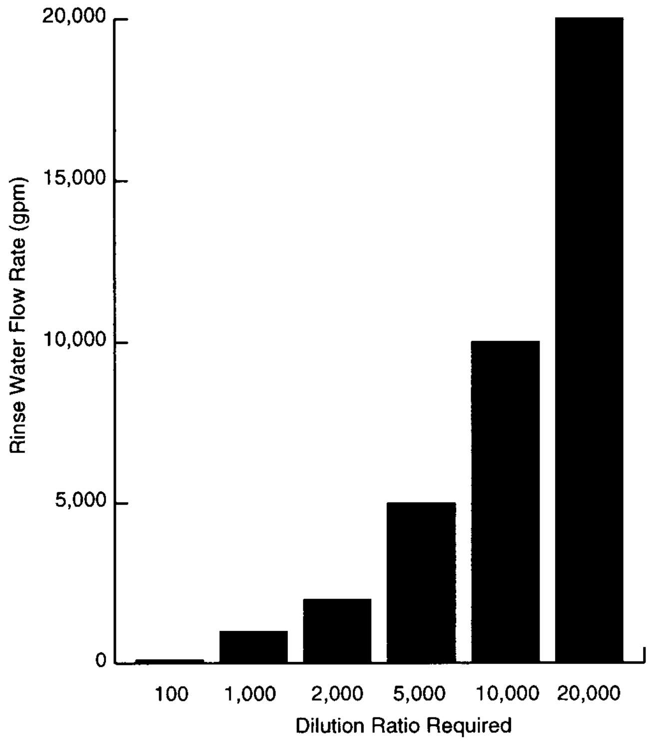


Figure 7-4. **Graph of rinse water flow rate required to dilute drag-in stream at 1 gal/min for first rinse bath only.**

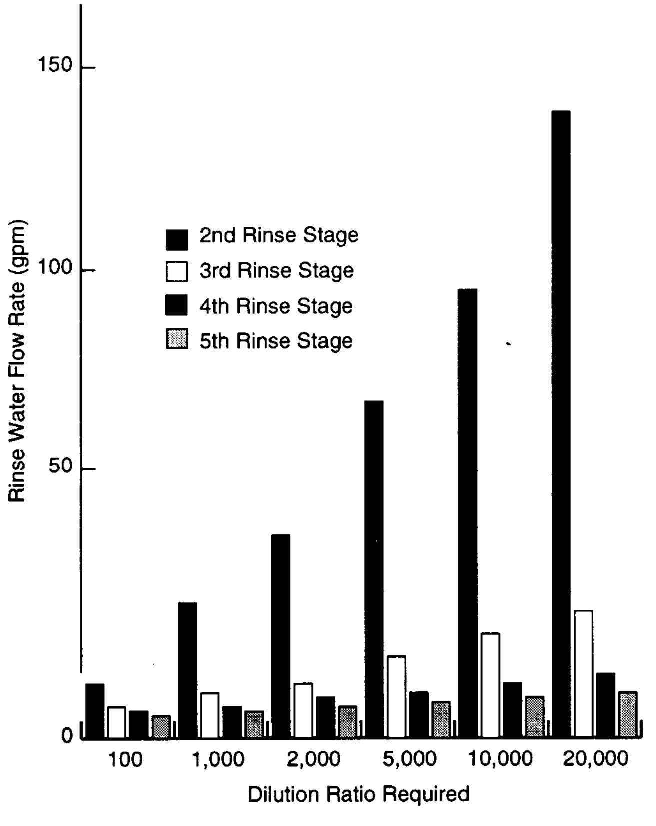


Figure 7-5. **Graph of counter-flow rinse water flow rate required to dilute drag-in stream at 1 gal/min for subsequent rinse baths.**

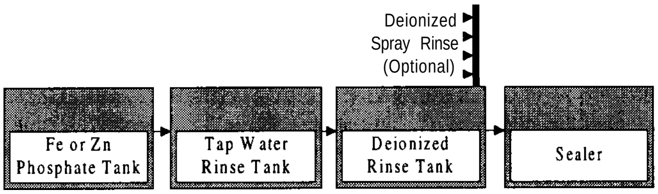


Figure 7-6. **Schematic of post-phosphating rinsing process with sealing rinse bath.**

Many companies omit the sealing stage, lowering the corrosion resistance provided by the phosphate coating. Typically, however, sealing rinses are a cost-effective addition to a pretreatment process line, given that rinse additives are inexpensive to use in low concentrations (i.e., a few ounces per gallon of rinse water) and the rinse stages are static (i.e., no overflow from the bath). Depending on the volume throughput of workpieces and the condition of drag-in from the previous stage, a sealing tank can have a useful life of several weeks before it must be replaced.

7.3.2 Chromate-Based Sealing Rinses Versus Nontoxic Alternatives

The sealing rinse stage in the paints and coatings process raises important considerations in terms of pollution prevention. The operator must balance tradeoffs between the use of chromate additives (i.e., hexavalent and trivalent chromium), which can be highly toxic, and nonchromate alternatives, which at present are generally less effective.

7.3.2.1 Chromate-Based Sealing Rinses

Operators have used chromate-based rinses for many years as an effective means of sealing the phosphate coating on the workpiece. Chromate rinse additives are based on either a hexavalent or trivalent chromium (i.e., Cr^{6+} or Cr^{3+}). While both forms are pollutants of concern, hexavalent chromium is particularly toxic and is a suspected carcinogen; thus, residuals must be disposed of as hazardous waste, which can add significant costs to the paints and coatings process.

Consider, for example, a situation in which all of the exhausted chromate-containing rinse water held by a 2,000-gallon immersion tank must be disposed of as a hazardous waste in 55-gallon drums, unless the wastewater is first treated. In 1995, the cost of disposing of a 55-gallon drum of liquid hazardous waste approached $600. Thus, the total cost to dispose of the entire tank of rinse water could exceed $21,000. If the operation's rinse water is replaced frequently, the annual cost of disposal could be significant. Moreover, the operator is responsible for tracking the hazardous waste from the "cradle to the grave."

Alternatively, the wastewater could be discharged to an onsite treatment plant for removal of the chromates and other contaminants by precipitation and filtration. The resulting sludge material would then need to be properly disposed of. The treated water could be recycled to the rinsing operation. While this approach is usually cost effective for large operations, most medium- and small-sized operations cannot afford the cost of an onsite treatment plant.

Another limitation of chromate use is that some formulations require that the workpiece be rinsed with clean water after the sealing rinse to remove unreacted chromate salts. Along with the cost of any equipment associated with adding this process step, costs associated with the generation of additional wastewater must be considered. One approach to minimizing the cost of this rinse step is to spray wash the workpiece while it is suspended over the sealing rinse bath. The tradeoff with this approach is that the spray rinse water is likely to gradually alter the chromate dilution ratio, limiting the useful life of the bath.

Given the limitations associated with the use of chromate-based rinse formulations, operators need to carefully weigh tradeoffs in terms of costs, pollution prevention, and the durability requirements of the finished workpiece. The determination of which sealing formulation to use must be made on a process-specific basis after thorough testing of various options.

7.3.2.2 Nonchromate Sealing Rinses

Although several nonchromate sealing formulations have been developed, their effectiveness for enhancing the durability of a finished workpiece as compared with chromate-based sealers has yet to be fully established (3). Nonetheless, when the finished workpiece will be used in applications requiring less-demanding corrosion resistance, nonchromate sealers can present an-attractive alternative. Also, available high-performance coatings (e.g., epoxies and polyurethanes) have corrosion-resistance properties that allow operators to offset potential deficiencies associated with nonchomate sealers.

The great advantage that nonchromate sealers hold over chromate-based formulations is that they are nontoxic. Thus, an operator can realize significant benefits by reducing or eliminating the need to dispose of hazardous residuals.

A related advantage is that often no clean-water rinsing of the workpiece needs to be performed after use of a nonchromate sealer. Indeed, post-sealing rinsing may harm the workpiece because it can wash away the protective film on the piece's surface. Thus, an operator can realize process savings in terms of wastewater minimization.

When determining whether to use a nonchromate sealer, the operator needs to weigh these potential advantages against the quality requirements of the finished workpiece. Before incorporating a nontoxic sealer into a paints and coatings process, an operator should thoroughly test the formulation in terms of the workpiece's specifications.

7.4 Case Example

Navistar International Transportation Corp., a manufacturer of truck cabs, has reported on its program to minimize pollution of all media (4). The truck cabs enter the pretreatment process via a two-stage alkaline degreaser. Stage 1 operates optimally at a pH of 10.5 and with an alkalinity range of 6 to 10. When analytical testing finds the total alkalinity to fall below 6, the degreaser is no longer considered effective. Formerly at this point, a portion of the tank would be dumped. To optimize the performance of Stage 1, the manufacturer would allow 2.5 gal/min of contaminated tap water from Stage 2 to overflow into Stage 1 while allowing an equal amount of water displaced from Stage 1 to overflow to the wastewater treatment system. In addition, the manufacturer would flush approximately 2,000 gal of water from the tank every 7 days, discharging it to the wastewater treatment system. Finally, every 45 days, Navistar dumped the entire contents of Stage 1, rinsed the tank with up to 17,000 gal of water, and then filled it with half the contents in Stage 2.

After examining the system further, Navistar discovered that it was not cost effective to cross-contaminate Stage 1 with water in Stage 2. Rather, after dumping, Navistar used fresh chemicals and water, extending the life of both stages from 45 to 90 days. Total cost savings for these modifications amounted to $9,384 per month.

Stage 3 of its pretreatment process comprises a municipal tap water rinse, which is contaminated with drag-in from the alkaline degreasing Stages 1 and 2. Navistar discovered that by allowing the cabs to drip drain over Stage 2 for an additional 1/2 minute, it could realize significant savings in the tap water rinse of Stage 3. Previously, Navistar had dumped this stage arbitrarily on a 14-day schedule. After performing process control laboratory tests on the alkalinity of the bath, however, it was able to decrease the dumping schedule to every 30 days. Apparently, this resulted in a 50-percent reduction of contaminated water sent to the wastewater treatment system.

Navistar performed a similar modification regarding the post-phosphating rinse stage. Process line operators had been arbitrarily dumping Stage 6 on a 14-day schedule. They found, however, that by monitoring the level of contaminants in this stage, they could decrease the frequency of dumping to between 90 and 120 days.

In the past, the sealing rinse was conducted with municipal tap water, and Navistar dumped this tank every 30 days because of unacceptably high levels of water contamination. The company found that by making up this bath with a 50:50 mix of municipal water to deionized water, it could increase the bath life by 50 percent, resulting in a cost savings of approximately $8,000 per month. This process modification was made based on information on the minimal cost of generating deionized water.

Navistar uses an electrocoating tank to apply primer. A considerably more expensive batch process treats some of the wastewaters from the primer process. Previously, the deionized water from the two rinse stages preceding the electrocoating line also overflowed to the same waste treatment process as that used for the electrocoat wastewater (analyte). Navistar discovered that it was not necessary to route the waste deionized water to this more expensive treatment process. Instead, it dumps water to its more general industrial wastewater treatment system. This minor modification further reduced treatment costs by $306 per month.

7.5 References

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Chapter 8
Abrasive Blast Cleaning of Metal Surfaces: Process Efficiency

8.1 Introduction

8.1.1 Pollution Prevention Considerations

Abrasive blasting is widely used in the paints and coatings industry as a means of cleaning metal workpieces and preformed materials. If blast cleaning operations are not carefully implemented and monitored, however, quality control problems can result that undermine process efficiency and lead to excess waste. A critical factor in blast cleaning is selection of an abrasive media that will yield a blast profile appropriate to the thickness of the primer coating. When an abrasive raises peaks on the substrate that protrude through the coating, flash rusting can result, especially if primed workpieces are temporarily stored outdoors. Rusting generally necessitates the reworking of pieces, adding process costs associated with material, labor, and waste management.

An efficiently run blasting operation also can yield process savings related to the cleaning media. Similar to aqueous degreasing operations, most of the dry media used in abrasive blasting can be recycled. Indeed, many operations include a degreasing step in the process line to maximize the blast media's reuse potential. By reusing abrasives, an operator can minimize the generation of the significant amounts of waste represented by spent media. Other variations include adding a phosphating step for further enhancing mechanical adhesion of the coating system.

Compared with degreasing, the abrasive blasting process can be time consuming and labor intensive; moreover, blasting can involve the risk of warping the workpiece. Thus, facility operators generally opt for this cleaning approach only when workpieces are too large to be immersed or effectively sprayed with a degreasing formulation. An incidental benefit of abrasive blasting, however, is that the considerable volume of wastewater generated with other cleaning methods is avoided.

These pollution prevention considerations are presented in this chapter in the context of process efficiency. An important overriding consideration in this discussion is right-first-time processing, which calls for designing and monitoring operations to ensure that reworks, and associated costs and pollutants, are minimized.

8.1.2 Decision-Making Criteria

Decision-making criteria relevant to process efficiency in the abrasive blast cleaning of metal surfaces, as addressed in this chapter, are highlighted in Table 8-1.

8.2 Process Basics

8.2-1 Introduction

Abrasive blasting is a method of cleaning corrosion and other contaminants from previously uncoated metal substrates before applying a primer-topcoat system. Blast cleaning also is used to remove failed or aged coatings from substrates before repainting (i.e., paint stripping), as discussed in Chapter 14.

In abrasive blasting, mineral and metallic abrasives, such as steel shot or mineral grit, are directed or propelled from a hose at a substrate using a high-pressure pneumatic system (Figure 8-1). The line operator holds the blasting nozzle a few inches from the substrate while directing the blast to all areas of the workpiece.

As a cleaning approach for substrates that have not been previously painted, abrasive blasting is used primarily for workpieces that are too large and heavy to be pretreated using immersion or spray degreasing processes.' Nonetheless, many operations degrease workpieces to the extent possible before subjecting them to blasting in order to minimize contamination of an abrasive media that will be recycled. Even when abrasive blasting is used in conjunction with a degreasing or a phosphating stage (see Section 8.4 on process variations), the operator is likely to realize some incidental benefits in terms of lower water-use requirements and thus lower wastewater generation.

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[1] As noted in Chapter 5, "degreasing" is used generally in this document to refer to the various liquid/vapor methods used in paints and coatings operations to clean substrates. The author recognizes that some operators use the term degreasing to refer specifically to vapor degreasing.

Table 8-1. Decision-Making Criteria Regarding Abrasive Blasting Processes

Issue	Considerations
Do workpieces have a steel substrate of sufficient thickness (>14 gage) to allow for abrasive blasting without warping surface?	• If so, consideration should be given to this approach as an alternative to pretreating workpieces with a chemical process.
Do workpieces need to be blast cleaned even though they have sections of thin steel substrate (<74 gage)?	• If so, it might be necessary to use a fine-mesh abrasive and to experiment with different blasting pressures to avoid warping the workpiece.
Will a liquid primer be applied?	• If so, select an abrasive (or blend of abrasives) that will yield a blast profile that can be completely covered by the film thickness of the coating. An angular profile, for instance, can be particularly difficult to cover and may require a second coat of primer. • Workpieces should be primed within 4 hours (but not longer than 8 hours) after abrasive blasting, depending on the ambient environment. For example, if blasted workpieces will be exposed to a marine or chemical environment, the interval should be shortened to avoid the onset of corrosion. • Consideration should be given to degreasing workpieces before blasting so that the abrasive media can be kept clean for recycling in the blasting process. • The use of wash primers, which tend to have a high VOCs content, should be avoided as a pollution prevention measure.
Will a zinc-rich primer be applied to workpieces?	• If so, workpieces should not undergo phosphating or wash priming; to be effective the zinc-rich primer must be in direct contact with the metal surface. • Given the importance of establishing direct contact between the primer and the substrate, workpieces should be degreased prior to blasting. • The blast profile should be sufficient (1.5 to 2.5 mils) to facilitate good mechanical adhesion between the primer and the substrate. (It is strongly recommended that the operator consult with **a** vendor when establishing the profile specification.) • Because workpieces receiving a zinc-rich primer are likely to provide corrosion resistance in aggressive environments, they should be cleaned to a near-white or white metal finish.
Can the operator select from a range of abrasives?	• If so, an abrasive with the lowest dusting characteristics and the highest recycle rate should be selected. (It may be necessary to consult with a vendor when choosing an abrasive.)
Are workpieces currently degreased prior to abrasive blasting?	• Consideration should be given to degreasing workpieces before blasting so that the abrasive media can be kept clean for recycling in the blasting process. • Without including a degreasing stage, abrasives can transfer contaminants from one workpiece to another and even imbed them in the substrate.

Abrasive blasting is used primarily to remove such surface contaminants as carbon deposits, scale, chemical impurities, and rust as well as oil and grease. It also can be used, however, to physically alter the surface of a workpiece to encourage good adhesion between the coating system and the substrate. For example, an operator might blast a metal surface with an abrasive to accomplish the following:

- Create a surface profile for optimum coating adhesion.
- Reduce design weights, porosity, friction, or susceptibility to corrosion.
- Strengthen the surface by peening.
- Add fatigue resistance.
- Remove surface irregularities.
- Correct distortions.

The discussion in this chapter, however, primarily focuses on blast cleaning. For more detailed discussions about other uses of abrasive blasting, see References 1,2, and 3.

8.2.2 Abrasive Blasting Systems

Blast cleaning is conducted using a pneumatic system that mixes the abrasive media and pressurized air through a valve at the base of the unit. Typically, systems force the media out the blasting nozzle with 100 psi of pressure (4); the speed at which the media travel is directly related to particle mass. Thus, the blasting efficiency of a particular media can be determined using the following equation, which relates mass to kinetic energy and velocity (5):

Impact energy = ½ mass x velocity*

Based on this equation, if mass is doubled, impact energy is also doubled. Similarly, if air pressure is increased, velocity also increases. Thus, if the media's velocity is doubled, the impact energy is quadrupled. Given that the production rate is proportional to the impact energy, if the impact energy is quadrupled, then

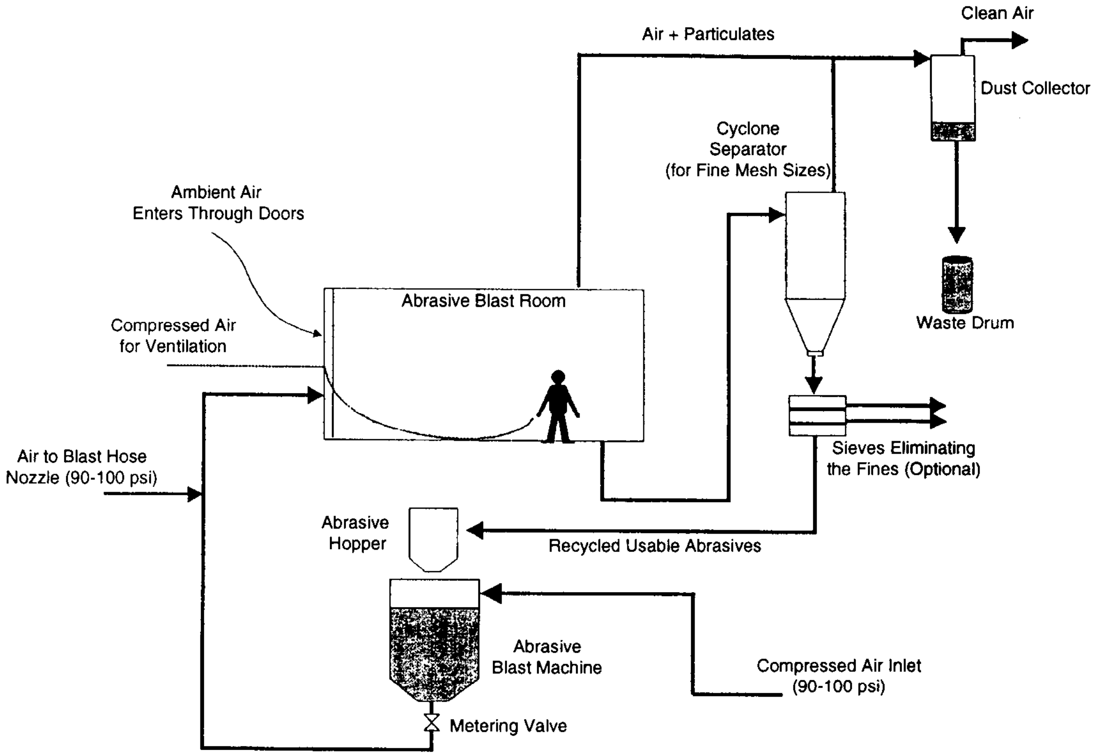

Figure 6-1. Schematic of an abrasive blasting operation with a media recovery system.

production rate (i.e., the blasting speed) increases by the same amount.

Depending on the size of the piece to be cleaned, abrasive blasting operations can be conducted within a cabinet or in a blast room. Cabinets, which are used for cleaning small parts, allow the line operator to manipulate the blasting nozzle from outside the enclosure by inserting his hands into protective gloves attached to the inside of the unit. Blast rooms are large enclosures that can accommodate both a full-size workpiece (e.g., weldments, subassemblies) and the line operator wearing protective gear. Both cabinets and blast rooms can be relatively simple enclosures or they can be equipped with powered turntables, media recovery systems, and dust filtering mechanisms (i.e., cyclone separators).

Conventional pneumatic blasting systems facilitate delivery of the media with a configuration that allows gravity feed from the hopper. Because such systems allow the line operator to precisely control air pressure, cleaning of the substrate tends to be more uniform and higher production rates can be achieved, particularly when heavier abrasives are used. Nonetheless, favorable results can be achieved with a lightweight abrasive, given that conventional systems can deliver most media to the substrate with high-impact energy.

In contrast, induction feed systems include a venturi at the nozzle to create a suction that draws the abrasive media from the feedstock without the benefit of gravity. Such systems generate less-constant blasting pressure and thus generally yield lower production rates. Nonetheless, they have certain advantages over conventional systems. For example, they are less expensive and require minimal maintenance; they are recommended for operations with space limitations because the units are smaller; and they can be readily modified for continuous operation, eliminating the need to occasionally stop operations to refill the media hopper.

8.2.3 Media Recycling

Wastes generated by the abrasive blasting process can be significantly controlled if a recyclable media is used. Typically, the spent media itself represents the greatest volume of waste from blasting operations. Of the various angular grit media, steel grit has the highest recycle rate and is less expensive than, for instance, sand and aluminum oxide (Table 8-2). The media with the lowest recycle rate is sand, which is generally discarded after one use. In cases where an abrasive is used in conjunc-

Table 6-2. Recycle Frequency of Abrasives (6)

Type of Abrasive	Recycle Times
Sand	1
Garnet	6-8
Aluminum oxide	10-15
Steel grit	>200
Chilled cast iron	50-100

tion with a toxic pretreatment chemical, the media can become contaminated and require special handling.

Grit abrasives are recycled into the blasting process after dust and fines have been removed via airwashing in an abrasive recovery system. In a typical blast cleaning operation with a media recovery system (i.e., based on screw conveyor, elevator, scraper floor, or pneumatic technology), waste can be reduced by more than 80 percent when steel grit is used (7).

Pneumatic abrasive recovery systems are one of the most effective approaches for removing dust and other contaminants from blasting media (6). Typical pneumatic systems draw up the media from the blasting room or cabinet floor with vacuum hoses by means of electrically powered impellers. The media is fed into a chamber where particles are separated out via centrifugal force. Heavier particles and debris that are thrown to the outer perimeter of the chamber swirl downward to a mesh screen, through which the abrasive passes to a hopper (Table 8-3). Dust and lightweight particles circle around the center of the chamber where they are captured by a suction tube.

Table 8-3. Selected Screen Sizes (2)

NBS Screen No.	Screen Size (mm)	Screen Size (in.)
7	2.8	0.1
8	2.4	0.1
10	2.0	0.1
12	1.7	0.1
14	1.4	0.1
16	1.2	0
18	1.0	0
20	0.9	0
25	0.7	0
30	0.6	0
35	0.5	0
40	0.4	0
45	0.4	0
50	0.3	0
80	0.2	7.0×10^{-3}
120	0.125	4.9×10^{-3}
200	0.075	2.9×10^{-3}

NBS = National Bureau of Standards

8.2.4 *Blast Profile as a Critical Factor*

Many abrasive blasting media cut into the substrate somewhat as they clear away hard mill scale and corrosion products (i.e., rust). This gives the workpiece surface a rounded or angular profile (i.e., the blast profile). As a result, the applied primer coating usually can establish a firm mechanical bond with the substrate (see Section 8.4 on process variations). This profile must be appropriate to the dry-film thickness of the primer coating. If the profile is too coarse, flash rusting can occur where the peaks of the profile protrude through the primer. For example, the blast profile of a substrate should be well below 2 mil (i.e., 2 thousandths of an inch) if the primer that will be applied has a dry-film thickness in range of 1.0 to 2.0 mil. The ability of a primer coating to thoroughly cover a blast profile also relates to the primer's drying time. A fast-drying formulation may set up before the coating can flow off the peaks and into the valleys of the profile. Conversely, a slow-drying primer can run off the peaks entirely and well up in the valleys.

If a primer coating does not thoroughly cover the peaks of a substrate's blast profile, flash rusting can occur, especially on large weldments and workpieces that must be stored outdoors where they may be exposed to excess moisture. Often, the line operator will return such rusted pieces to the blast room for either partial or complete reworking, resulting in excess costs and waste generation. If the flash rusting is not removed before the topcoat is applied, the coating system is likely to fail prematurely, possibly by delaminating from the surface.

The blast profile is controlled by the size and shape of the abrasive, the size of the blasting nozzle, and the blasting velocity and air pressure. During abrasive blasting, the line operator should occasionally check that the appropriate blast profile is being achieved. This can be done either visually using a surface profile comparator (i.e., a profilometer) or by measuring the profile with a roughness gauge, both of which are available from industry sources (8, 9).

8.2.4.1 Case Example: Coating Failure Due to an Extreme Blast Profile

A company in Florida installed a new coating facility and purchased equipment for abrasive blast cleaning all of its large steel weldments. Because of the high humidity in Florida, the company applied a relatively expensive, high-quality epoxy primer directly over the abrasive-blasted steel. After the primer had cured, the steel weldments were taken to outside storage, where they awaited final assembly and testing.

Within 24 to 48 hours after the weldments were exposed to the outside environment, entire surfaces began to show signs of flash rusting. The rusted weldments were reworked in the blasting room and a fresh coat of primer was applied.

An inspection of the substrate using a low-power magnifying glass showed that the peaks of the blast profile were protruding through the primer. The profile was measured at 2.5 to 3.5 mil and the primer dry-film thickness at only 0.8 to 1.0 mil.

The problem was then solved by changing the application parameters, which favored a shallower profile. Although this process change made the blasting operation more time consuming and labor intensive, costs were more than offset by avoiding the reworking of rusted weldments. Changing the application parameters required no major management decision.

Although the company had carefully planned operations at the new facility and specifications had called for a blast profile less than 1.5 mil, no quality control checks of the blasting process were conducted. Thus, no one noticed that the profile was out of specification. The problem could have been avoided had better management practices been enforced.

The corrective action was taken to resolve a quality control problem, but the operation also benefited by minimizing pollution generation associated with reworking the weldments. This was an important unanticipated benefit, especially because the company operated in an area with strict local environmental requirements.

8.2.5 Types of Abrasive Media and Selection Criteria

The six most commonly used abrasive media are (6):

- Steel shot: Small, spherical particles of hypereutectoid steel (i.e., containing more than 0.8 percent carbon) in its fully heat-treated condition. Steel shot has a uniform structure of finely tempered martensite (i.e., the hard constituent of quenched steel), which provides optimum resilience and resistance to fatigue. Thus, it is particularly suited to shot peening and considered an optimum abrasive for wheel blast applications.

- *Cast* steel *grit:* A high-carbon content, angular pellet. Depending on the hardness selection, this abrasive is effective, for instance, in removing scale or etching the substrate to enhance its profile. Steel grit is one of the most commonly used abrasives for preparing steel substrates to receive a coating (6).

- *Aluminum oxide:* Fused alumina grains that are angular and characteristically hard and resilient, providing particularly fast cutting action.

- *Garnet grit:* A mineral abrasive with sharp angular characteristics that provides fast cutting action and has a long service life.

- *Mineral slag:* A diamond-like, angular abrasive that is without free silica and does not attract moisture, providing fast cutting action.

- *Chilled iron grit:* The lowest cost mineral abrasive. It is particularly recommended for difficult cleaning jobs.

- *G/ass beads:* Small, lightweight, spherical media used primarily on nonferrous metals for shot peening and surface finishing. Predominantly used in the aircraft and automotive industries.

Table 8-4 lists selection criteria specific to various abrasive blasting media. For some blasting operations, assorted abrasives are mixed so that the media include different grit sizes. More general factors that the operator should consider when choosing an abrasive include the following:

- *Compatibility:* The mineral or metallic abrasive should have characteristics similar to the metal substrate to avoid the likelihood that galvanic corrosion will result if some of the blasting material becomes imbedded in the surface of the workpiece. For example, a steel abrasive should not be used on an aluminum substrate. Moreover, too hard an abrasive can result in distortion of the workpiece surface.

- *Shape:* The shape of the abrasive relates to its cutting ability and therefore the blast profile. Thus, because steel shot is round in shape, it will produce a profile characterized by rounded valleys. In contrast, an abrasive with an angular shape will yield a sharper profile. For example, an operator might use cast steel grit when a zinc-rich primer will be applied, because such primers rely on a mechanical bond with the substrate.

- Size: The grain size of the abrasive media used must be consistent with the specified blast profile so that the primer coating will thoroughly cover the substrate. Smaller grain sizes are used to avoid either cutting too course a profile in the substrate or warping workpiece areas made with a thin metal. Tables 8-5 and 8-6 are examples of size specification sheets available from media vendors.

- Low *dust generation:* The amount of dust caused by fragmentation of the abrasive should be minimal to reduce pollution of the ambient air with particulate matter. When a metallic abrasive is used, dust should also be minimized to avoid encouraging galvanic corrosion from particulate left on the substrate. Additionally, an excess of metal fines mixed into a recycled medium can undermine blasting efficiency.

- *Recyclability:* Preferably, an abrasive will have a high reuse rate, minimizing process costs and waste generation.

- Cost: Cost comparisons should include consideration of all process factors, including the cost of rejected/

Table 8-4. Guide for Selected Abrasive Media

	Stainless Cut Wire	Steel Shot	Steel Grit	Aluminum Oxide	Silicon Carbide	Garnet
Finishing	Yes	Yes	Yes	Yes	Yes	Yes
Cleaning/Removal	Yes	Yes	Yes	Yes	Yes	Yes
Peening	No	Yes	No	No	No	No
Surface profiling (Etch)	Yes	No	Yes	Yes	Yes	Yes
Working speed	Med	Med	Med-Hi	High	Very-Hi	High
Recyclability	High	Very-Hi	Very-Hi	Med-Hi	Med-Lo	Med
Probability of metal removal	Med-Hi	Very Lo	Med	Med-Hi	Med-Hi	Med
Hardness, MOH scale (Rockwell Rc)	6-7.5	6-7.5	6-7.5	8-9	9	8
Bulk density (lb/cu ft)	280	280	230	125	95	130
Mesh sizes	20-62	8-40	10-325	12-325	36-220	16-325
Typical blast pressures (psi)	50-90	50-90	50-90	20-90	20-90	30-80
Shape	Angular	Spherical	Angular	Angular	Angular	Angular

Source: industry literature.

Table 8-5. Sample Specification Sheet for Steel Shot (2)

Product	7	8	10	12	14	16	18	20	25	30	35	40	45	50	80	120	200
S780			0.85 min	97% min													
S660				85% min	97% min												
S550					85% min	97.5% min											
S460				5% max		85% min	98% min										
S390					5% max		85% min	96% min									
S330						5% max		85% min	96% min								
S280							5% max		85% min	96% min							
S230								10% max		85% min	97% min						
S170									10% max			85% min	97% min				
S110											10% max			80.5 min	90% min		
S70													10% max		80.5 min	90% min	
Screen number	7	8	10	12	14	16	18	20	25	30	35	40	45	50	80	120	200
Screen size mm	2.8	2.4	2	1.7	1.4	1.2	1	0.9	0.7	0.6	0.5	0.4	0.4	0.3	0.2	0.125	0.075
Screen size inches	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0	7.0e-03	4.9e-03	0.0029

reworked pieces and recyclability of the media. Research has shown, for instance, that overall operational costs when using a non-recyclable abrasive such as slag can be seven times higher than when using a recyclable media such as steel grit, even though the per pound cost of the grit may be nine time higher than the slag (10).

8.2.6 Blast Cleaning Standards

Industry standards have been established regarding the cleanliness of a substrate following blast cleaning operations. The cleanliness coding of various rating systems are presented in Table 8-7. The ratings are portrayed pictorially in standards compilations and based on the following paraphrased industry-wide definitions:

Table 8-6. Sample Specification Sheet for Steel Grit (2)

Product	7	6	10	12	14	16	18	20	25	30	35	40	45	50	80	120	200	325
G.12				0.8	0.9													
G.14					80%	0.9												
G.16						0.75	0.85											
G.18							0.75		0.85									
G.25									0.7			0.8						
G.40												0.7		0.8				
G.50														0.65	0.75			
G.80															0.65	0.75		
G.120																0.6	70%	
Screen number	7	8	10	12	14	16	18	20	25	30	35	40	45	50	80	120	200	325
Screen size mm	2.80	2.4	2	1.7	1.4	1.2	1	0.9	0.7	0.6	0.5	0.4	0.4	0.3	0.2	0.1	0.075	0.045
Screen size inches	0.111	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.0049	0.0029	

Table 8-7. Comparison of Designations for Blast Cleaning Finishes

	Brush-Off	Commercial	Near-White Metal	White Metal
Steel Structures Painting Council (USA)	SSPC-SP7	SSPC-SP6	SSPC-SP10	SSPC-SP5
National Association of Corrosion Engineers (USA)	NACE No. 4	NACE No. 3	NACE No. 2	NACE No. 1
Swedish Standards Organization	SA-1	SA-2	SA-2½	SA-3
United Kingdom Standards (BS 4232)		3rd Quality	2nd Quality	1st Quality

- Brush-off: The cleaned surface, when viewed without magnification, must be free of all visible oil, grease, and dirt as well as loose mill scale, rust, and previously applied coatings. Adherent mill scale, rust, and old coatings may remain on the surface. Such contaminants are considered adherent if they cannot be lifted with a dull putty knife.

- Commercial: The cleaned surface must be free of all visible oil, grease, dirt, and dust as well as mill scale, rust, and previously applied coatings. Generally, evenly dispersed, very light shadows, streaks, and discolorations caused by stains of mill scale, rust, and old coatings may remain on no more than 33 percent of the surface. Also, slight residues of rust and old coatings may be left in the craters of pits if the original surface is pitted.

- Near-white metal: The cleaned surface must be free of all visible oil, grease, dirt, and dust as well as mill scale, rust, and previously applied coatings. Generally, evenly dispersed, very light shadows, streaks, and discolorations caused by stains of mill scale, rust, and old coatings may remain on no more than 5 percent of the surface.

- White metal: The cleaned surface must be free of all visible oil, grease, dirt, and dust as well as mill scale, rust, and previously applied coatings. No traces of contaminants may remain on the surface.

Pictorial portrayals of abrasive cleaning standards are compiled in the following trade association documents:

- Steel Structures Painting Council Visual Standard (SSPC-VIS-1-89), Steel Structures Painting Council, Pittsburgh, PA.

- NACE Visual Standard for Steel Surfaces Airblast Cleaned With Sand Abrasive; NACE Standard TM-01-07, National Association of Corrosion Engineers, Houston, TX.

- Swedish Standard (05/5900/67), Swedish Standards Organization (available from American Society for Testing Materials, Philadelphia, PA).

- United Kingdom Standards (BS 4232).

The total cost of a standards compilation and a blast profile comparator (see Section 8.2.3) is approximately $300.

8.3 Best Management Practices

The following management practices are recommended for enhancing abrasive blasting process efficiency:

- To maintain quality control, facility operators should periodically inspect surfaces to ensure that industry blast cleaning standards are being met; also, they should occasionally measure the blast profile to guard against the potential for flash rusting.

- To avoid flash rusting generally, line operators should apply a primer coating to clean surfaces within 8 hours of abrasive blasting; in high-humidity environments, a primer should be applied within 4 hours. If near-term priming is not feasible, line operators should wrap and/or store the cleaned workpiece under cover or apply a temporary corrosion preventive, even though this coating will need to be removed through degreasing before application of a topcoat (see Chapter 5).

- To avoid the deposition of fingerprints and other incidental contaminants when processing white-metal workpieces, operators should require workers to wear latex gloves when handling the pieces after blast cleaning.

- To ensure consistent control of the blast cleaning process, operators should thoroughly train relevant workers, even though turnover tends to be high for such operations. Training materials (e.g., videos) are available from both the Steel Structures Painting Council and the National Association of Corrosion Engineers.

- To avoid contamination of the media feedstock, facility operators should ensure that moisture is not condensing on the hopper surfaces. Also, air supply lines should be equipped with oil and water traps.

- To ensure optimum mixing of pressurized air and the abrasive media, operators should equip the blasting system with a hopper that has a concave head and a cone-shaped bottom to facilitate feed flow. Similarly, hose couplings should be flush with the inside of the hose and sized to minimize obstruction and leakage of pressure. Additionally, the mixing valve should be periodically cleaned.

8.4 Process Variations (With Case Examples)

8.4.1 Abrasive Blasting Preceded by Degreasing

Many paints and coatings operations subject workpieces to abrasive blasting as well as degreasing in one process line. In most cases, these two pretreatment stages are used in conjunction to minimize contamination of an abrasive that will be recycled in the blasting operation. If a relatively expensive abrasive is being used, such as steel shot, the facility operator will have a strong incentive to optimize its useful life. With a less-expensive media, such as sand, the operator will need to weigh the tradeoff between the cost of replacing the media more frequently and the water-use and wastewater-handling costs associated with degreasing (see Chapter 5).

If the facility operator chooses to recycle the blast media without degreasing workpieces, the recycled abrasive is likely to entrain grease, metal fines, and other contaminants and then deposit them on the surface of the next uncoated piece. Coatings that are applied over such contaminants will have a high potential for premature failure, either gradually (by spalling) or catastrophically (by delaminating). Whereas the cost of taking steps to prevent such failures may be preclusive for some low-value end products sold in price-sensitive markets, achieving a reasonably durable coating is likely to be a requirement for many operations.

In most situations, the roughening of the metal substrate that can be achieved in abrasive blasting is particularly important for enhancing adhesion. With marine coating systems, for example, the zinc-rich primers specified by industry standards provide superior corrosion resistance but have poor adhesion properties. Thus, the substrate profile resulting from abrasive blasting enhances the ability of the epoxy and polyurethane enamel coatings applied over the primer for marine workpieces to establish a strong mechanical bond. The danger is that too high a blast profile would lead to premature corrosion of the substrate when subjected to marine environments.

Factors a facility operator should consider when deciding on whether to add a degreasing stage include:

- Regulations concerning VOC emissions and wastewater treatment.
- Equipment and floor-space requirements.
- Costs versus benefits in terms of the overall operation.

8.4.1.1 Case Example: Coating Failure Due to Contamination of Recycled Media

A major fabricator of railcars installed an automatic system for blast cleaning steel plates upon delivery to the facility. Immediately after blasting, a corrosion-resistant primer was applied using an airless spray gun. The primed plates then were stored until required for fabrication. After assembly, a second coat of primer was applied, followed by a colored, decorative topcoat.

Occasionally, the operator discovered craters in the paint film, requiring that certain areas of painted pieces be reworked (i.e., scuff sanded followed by repainting). One day, however, the paint operator found that entire sides of several finished railcars had thousands of craters on the surface. The coatings on these cars had to be stripped and then reblasted, reprimed, and refinished.

On close analysis of the process, it was found that the abrasive media was picking up so much oil and grease over several months of recycling that the substrates were being recontaminated. The problem was easily solved by replacing the abrasive with new material. To prevent such coating failures in the future, the company added a pretreatment step for subjecting all steel plates to high-pressure, hot-water degreasing. In addition, kaolin powder was added to the abrasive to absorb any traces of oil or grease that might become entrained in the media.

The most important change to the process was the addition of aqueous degreasing. While this added to process costs, it prevented further failures and thus reduced the cost of labor and materials required to rework rejected paint finishes. With the degreasing step, the company needed to handle the large quantities of wastewater. This was accomplished, however, by directing the spent water to a settling tank, then skimming off oil and grease and adjusting the pH before discharge.

The problem could have been avoided had the company initially used better management practices. Until the catastrophic failures brought production to a halt, no one at the company had fully assessed the unnecessary costs and additional pollution generation incurred during the earlier months when sporadic failures had occurred.

8.4.2 Abrasive Blasting Followed by Phosphating

For some situations, subjecting workpieces to a phosphating stage after abrasive blasting is recommended. Although few operations use both of these stages in conjunction, this approach can yield a superior mechanical bond between the substrate and the coating system and thus improved corrosion resistance.

When workpieces are subjected to both abrasive blasting and phosphating, the operator should monitor the blast profile closely. Phosphate deposition can vary significantly depending on the profile of the substrate yielded by the blasting abrasive. A more pronounced blast profile will result in a heavier phosphate coating. For example, deposition of an iron phosphate can vary from 30 to 220 mg/ft^2 depending on the type of media used in blast cleaning.

8.4.2.1 Case Example: Coating Failure Due to Peening of the Substrate

A fabricator of steel cabinets intended to be used in all types of outdoor environments selected a powder coating process for finishing the workpieces. Because of major contamination on the substrate, the facility operator abrasive blasted the workpiece surfaces before applying an iron phosphate. The operator felt that the combination of the blast profile plus the phosphate deposition would benefit adhesion of the powder coating and provide enhanced corrosion resistance.

During accelerated environmental tests of the cabinets, however, the powder coating failed catastrophically due to poor adhesion. Extensive experimentation showed that a heavy phosphate coating was required for the cabinets to pass the tests. Further experimentation indicated that the shape and hardness of the abrasive selected were critical for accomplishing the appropriate phosphate deposition on the substrate; the steel surfaces were being peened, and this hindered the phosphate from adequately depositing on the surface. After a change to angular grit, which yielded a more active surface, the phosphate coating weight increased approximately threefold. With this pretreatment modification, the powder coating passed the accelerated testing.

The change of abrasive was accomplished within a few days and at little expense, and the problem of workpiece rejects was essentially eliminated.

8.5 References

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Section 3
Application Process Factors

Chapter 9
Transfer Efficiency as It Affects Air, Water, and Hazardous Waste Pollution

9.1 Introduction

9.1.1 Pollution Prevention Considerations

Of all the strategies available to minimize pollution in a paints and coatings facility, improving transfer efficiency is perhaps one of the most effective. Slight increases in transfer efficiency can result in significant pollution reductions as well as guaranteed cost reductions.

The concept of transfer efficiency is extremely simple: it is the ratio of the mass of solid coating deposited on a substrate to the mass of solid coating used during the application. It can also be defined in terms of volume. The following equations express these definitions:

$$\text{Transfer Efficiency} = \frac{\text{Mass } \textbf{solid} \text{ coating deposited}}{\text{Mass } \textbf{solid} \text{ coating used}}$$

or

$$\text{Transfer Efficiency} = \frac{\text{Volume } \textbf{solid} \text{ coating deposited}}{\text{Volume } \textbf{solid} \text{ coating used}}$$

To illustrate the importance of this concept, suppose that a spray painter applies a coating to a metal filing cabinet using a conventional air atomizing spray gun. The spray gun deposits much of the coating on the metal cabinet, but a significant amount of overspray is directed toward the spray booth filter or drops to the spray booth floor. Clearly, the overspray is wasted and represents the inefficiency of the spray application. Wasted overspray contributes to air, water, and hazardous waste pollution. It is evident, then, that making the process more efficient can directly benefit pollution prevention.

The definition of transfer efficiency does omit a couple of important related factors. First, transfer efficiency accounts for only the amount of solid coating (i.e., resins, pigments, extenders, and additives) that remains on the steel cabinet after the solvents have evaporated, and relates this to the total amount of solids that the spray gun applied. In both the numerator and denominator of the equation, therefore, the amount of solvent in the coating is not relevant.

Secondly, the definition of transfer efficiency does not account for the dry film thickness of the substrate coating. The following, which builds on the previous example, illuminates this distinct weakness in the definition:

> Suppose the spray painter who applied the previous coating to the metal filing cabinet applies a coating of 1 mil (1 mil = 0.001 inches) dry film thickness to the substrate. If the spray painter deposits 80 percent of the solid content of the coating onto the metal surfaces and wastes 20 percent in the spray booth, then transfer efficiency is 80 percent. Now, suppose that a second spray painter who is less experienced than the first applies the same coating to an identical filing cabinet. If he deposits twice as much coating (i.e., 2 mil dry film thickness), but he too deposits 80 percent of the solids to the surfaces, transfer efficiency would also be 80 percent.
>
> Thus, despite the fact that the second spray painter uses twice as much coating as did the first spray painter, the transfer efficiency for both spray painters is the same.

It is unfortunate that the definition does not encompass dry film thickness or the amount of solvent used. This chapter, however, explores many strategies for improving not only transfer efficiency, but overall efficiency of the coating application.

9.1.2 Decision-Making Criteria

Decision-making criteria relevant to transfer efficiency, as addressed in this chapter, are highlighted in Table 9-1.

9.2 Benefits of Improved Transfer Efficiency

Benefits associated with improving transfer efficiency include:

- Reduced air pollution (volatile organic compounds-VOCs).
- Reduced hazardous waste.
- Less frequent cleaning of guns, spray booths, and filters.
- Reduced use of chemicals in water-wash spray booths.
- Reduced discharge/treatment of water.
- Reduced costs.

Table 9-1. Decision-Making Criteria Regarding Transfer Efficiency

Issue	Considerations
Which spray guns are most efficient for specific workpieces?	• If workpieces are small (can fit into 12-inch cube) and require high or medium quality finishes, choose electrostatic, HVLP, conventional air atomizing, or air-assisted airless guns. • If workpieces are medium-sized (can fit into 24-inch cube) and require high quality finishes, choose electrostatic, HVLP, or conventional air atomizing guns. • If workpieces are medium-sized and require medium quality finishes, choose electrostatic, HVLP, conventional air atomizing, air-assisted airless, or, in some cases, airless guns. • If workpieces are large (cannot fit into 24-inch cube) and require high quality finishes, choose electrostatic, HVLP, or conventional air atomizing guns. • If workpieces are large and require medium quality finishes, choose electrostatic, HVLP, conventional air atomizing, air-assisted airless, or airless guns.
What easy-to-implement strategies can improve transfer efficiency?	• Stand closer to the workpiece. • Select the most efficient spray gun for the intended application. • Reduce fan width, as well as the extent of overspray due to fan width during first and last stroke. • Reduce atomizing air pressure (where applicable) and fluid pressure. • Space workpieces closer together. • Reduce air velocity in spray booth but not below OSHA recommended limits. • Avoid air turbulence in spray booth. • Reduce leading and trailing edges. • Optimize parameters when using electrostatic guns. • Do not apply thicker coating than is specified.
How should the transfer efficiency of the process be measured?	• If workpieces are small and lightweight (less than 70 pounds each), use the weight (mass) method. • If workpieces are small and heavy (greater than 70 pounds each) with simple geometry, use weight method by "wallpapering" with aluminum foil. • If workpieces are small with complex geometry but surface area can still be calculated, use volume method. • If workpieces are small with complex geometry but one cannot calculate surface area, a special protocol may need to be designed. • If workpieces are too large to fit onto balance and have simple geometry, use weight method by "wallpapering" with aluminum foil. • If workpieces are too large to fit onto balance and have complex geometry but surface area can still be calculated, use volume method. • If workpieces are too large to fit onto balance and have complex geometry but surface area cannot be calculated, a special protocol may need to be designed.

9.2.1 Reductions in Pollution and Related Factors

Small increases in transfer efficiency can result in great reductions in pollution. Table 9-2 presents the emissions of VOCs from a painting operation that uses a coating with a VOC of 3.5 lb/gal. The painters apply this coating to achieve a dry film thickness of 1.0 mil on the substrate.

To understand the significance of the calculations, consider only the first column, namely "Transfer Efficiency," and the last column, "Emissions of VOC/1,000 ft^2 of Coated Surface." The table includes the middle column because several VOC regulations are written in terms of lb VOC/gal Solids Applied.

Figure 9-1 is a graph based on the calculations of Table 9-2.

Table 9-2 and its corresponding graph can apply to a factory that must coat 1,000 ft^2 of metal surface each day. A novice painter who poorly handles the spray gun achieves a transfer efficiency of only 5 percent. He is able to deposit a coating film of 1 mil dry film thickness. In order to coat 1,000 ft^2 of surface, he emits 83.2 lb of VOC into the air. Suppose another novice painter can achieve a transfer efficiency of 10 percent. Although this is hardly better than the first painter's 5 percent, the second painter's emissions for the 1,000 ft^2 of coated surface is only 41.6 lb. Even though transfer efficiency increases by a very small amount, emissions are cut in half. As Figure 9-1 indicates, an increase in transfer efficiency from 5 percent to 10 percent is really very small and not difficult to achieve. As transfer efficiency continues to improve, probably with the use of more experienced painters or better equipment, VOC emis-

Table 9-2. Effect of Transfer Efficiency on VOC Emissions

Transfer Efficiency (%)	Emissions of VOC in lb VOC/gal Solids Applied	Emissions of VOC in lb VOC/1,000 ft^2 of Coated Surface
5	133.5	83.2
10	66.7	41.6
15	44.5	27.7
20	33.4	20.8
25	26.7	16.6
30	22.2	13.9
35	19.1	11.9
40	16.7	10.4
45	14.8	9.2
50	13.3	8.3
55	12.1	7.6
60	**11.1**	6.9
65	10.3	6.4
70	9.5	5.9
75	8.9	5.5
80	8.3	5.2
85	7.9	4.9
90	7.4	4.6
95	7.0	4.4
100	6.7	4.2
VOC of Coating	3.5 Ib\gal	
Dry Film Thickness	1.0 mil	

sions quickly drop to very small values (see Table 9-2 and Figure 9-1).

Moreover, if one of the painters uses a paint brush to apply the coating and achieves a transfer efficiency of 100 percent, yet can also apply the coating-at a uniform film thickness of 1 mil, his total VOC emissions for coating the same surface area is only 4.2 lb. While the first spray painter, whose transfer efficiency was 5 percent, emitted 83.2 lb of VOC into the air, the last painter who used a paint brush, emitted only 4.2 lb to do exactly the same job.

Of course, it is impractical to use a paint brush to apply all coatings. It is clear, however, that if using an efficient spray gun or other method of coating application can maximize transfer efficiency, an enormous reduction in pollution will result.

While it may not be practical or cost-effective to achieve transfer efficiencies of 80 percent or more under most circumstances, spray painters can often achieve transfer efficiencies in excess of 50 percent. As Table 9-2 notes, even a transfer efficiency of 50 percent causes emissions to drop to only 8.3 lb of VOC/1,000 ft^2 of coated surface.

While Table 9-2 and Figure 9-1 demonstrate only reductions of emissions into the air, obviously as transfer efficiency improves, the amount of overspray in the spray booth drops significantly. This translates into less frequent cleaning of the spray booth, as well as a reduction in the disposal of used dry filters (in dry filter spray booths) or of paint sludge (in water-wash spray booths). For water wash spray booths, improved transfer efficiency also reduces the use of chemicals needed to detoxify the paint sludge, and the discharge and treatment of water from the water trough.

9.2.2 Reduction in Costs

While increased transfer efficiency and reduced waste contribute to preventing pollution, they also result in reduced costs. In order to fully appreciate the impact transfer efficiency has on air, water, and waste pollution, as well as on costs, consider a spreadsheet that accounts for all factors. The tables in Appendix C serve this purpose.

The tables of this appendix present assumptions and calculations based on a relatively small operation which coats 100 widgets per day. Table C-l of the appendix provides a list of assumptions that are required to calculate cost savings due to improved transfer efficiency. Table C-2 provides the results of calculations that reflect the total cost for waste, filters, labor, and wasted paint when the transfer efficiency is 30 percent. Table C-3 is identical to Table C-2, except it lists the results when the transfer efficiency is 45 percent. Table C-4 provides the formulas that are used to perform the calculations.

Using the spreadsheet structure and calculations model presented in this Appendix, the reader can estimate transfer efficiency at his or her own facility. The reader can change any of the assumptions to see how effective, minor changes in the coating application which affect transfer efficiency can provide dramatic benefits.

Table 9-3 of this chapter presents the total waste costs of this same relatively small operation which coats 100 widgets per day. When the transfer efficiency of this operation is 30 percent, its annual waste costs are $102,750.62. If all of the assumptions remain the same but transfer efficiency increases reasonably from 30 to 45 percent, the operation can realize great savings (see Table 9-3) namely $48,928.87.

It is entirely possible to realize this cost savings without spending a single dime on spray or other equipment. With training, painters can probably achieve this conservative increase in transfer efficiency. In addition, along with the cost savings, a 15 percent increase in transfer efficiency contributes considerably to pollution prevention.

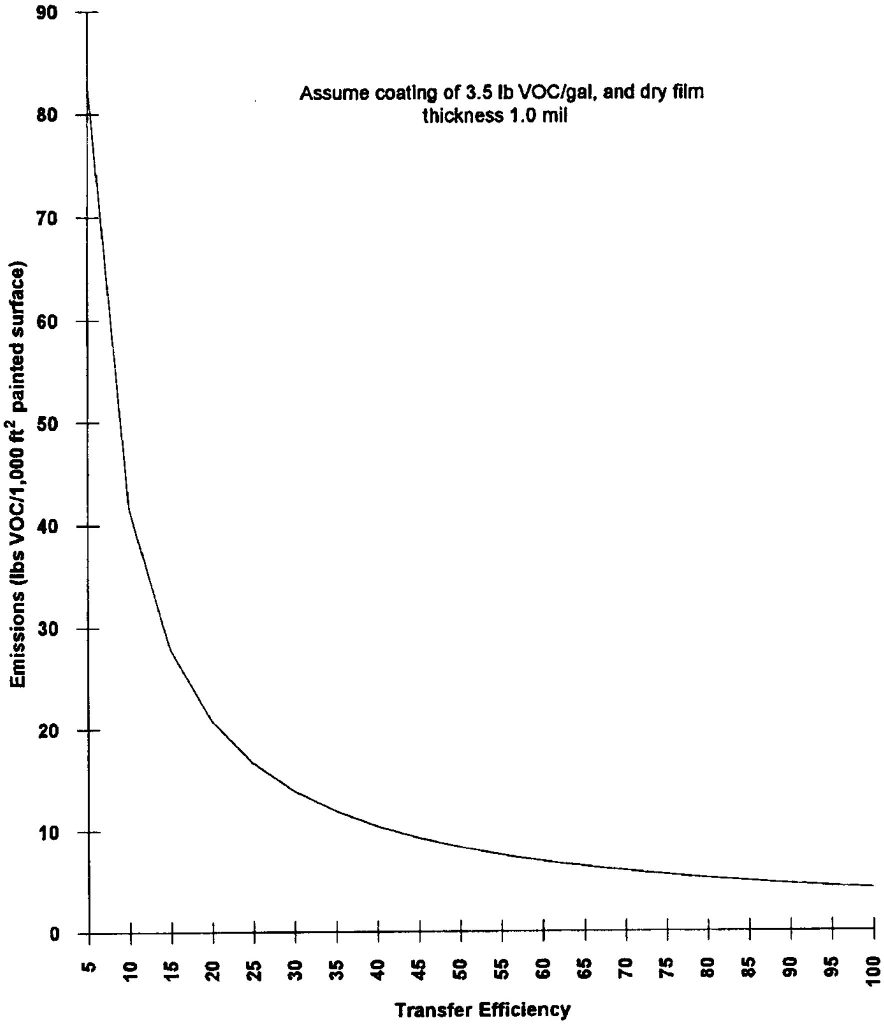


Figure Q-l. Effect of transfer efficiency on VOC emissions.

Table 9-3. Annual Cost Savings Due to Transfer Efficiency (TE) Improvement From 30% to 45%

	Waste Costs With TE = 30%	Waste Costs With TE = 45%	Savings Due to TE Improvement
Cost of waste + filters + labor	**$29.649.18**	**$15,530.52**	**$14,118.66**
Cost of wasted paint	$73,101.44	$38,291.23	$34,810.21
Total cost of waste	$102,750.62	$53.821.75	$48,928.87

9.3 Methods for Measuring Transfer Efficiency

9.3.1 Defining Parameters Before Commencing the Transfer Efficiency Test

Before deciding on whether an operation needs to improve its transfer efficiency, it is helpful to determine its current transfer efficiency. This section describes various testing methods available. Before conducting any transfer efficiency test, several parameters need to be established:

- Upon which parts will the test focus.
- Which coatings and spray guns will the test employ.
- Who will apply the coatings.
- How will the test simulate day-to-day production conditions.

After identifying the basic parameters, the paint operator must establish a fluid flow rate that is representative of day-to-day production. The operator needs to set the optimum air pressure for correct coating atomization and to adjust the coating viscosity and temperature to be representative of typical application conditions.

If using electrostatic equipment, the operator must confirm that the parts to be coated are properly grounded, that the coating has been adjusted so that its resistivity meets the manufacturer's recommendation, and that the air velocity through the spray booth is neither too high nor too turbulent.

Another decision to make before starting a transfer efficiency test is whether to use the weight (mass) method (most common) or the volume method.

9.3.2 *Using the Weight (Mass) Method*

Determining transfer efficiency on a weight or mass basis, as is usually the case, requires purchasing or renting an electronic balance capable of measuring to within 0.5 g. (In this document, the words weight and mass are synonymous. While scientists use mass, most others prefer to use weight.) Available balances can weigh as much as 154 kg (70 Ibs) with this accuracy. The balance must sit on a hard surface such as a metal table, concrete floor, or cement slab. Never place a piece of cardboard under the balance as it will lead to erroneous results.

In addition, the operator must shield the balance from all drafts that may occur on a factory floor, perhaps by surrounding the scale with large pieces of cardboard. The operator must also ensure that the pressure pot or coating reservoir is not too heavy for the balance and that the individual parts to be coated also fall within the maximum limit of the balance.

The balance should be set so that the air bubble in the bubble glass falls within the center of the glass. In addition, all four feet below the balance must be in firm contact with the ground or surface. Finally, the operator must calibrate the balance using standard weights which are often supplied by the balance manufacturer or rental company.

The cost to conduct a transfer efficiency test can be minimal. Companies can usually rent electronic balances for less than $300/week. A laboratory charge might run approximately $150/sample. The only other real expense involves in-house labor. Of course, if a company retains a consultant to conduct the test, costs might range from $3,000 to $5,000, depending on the complexity of the operation.

9.3.2.1 Measuring the Weight of Coating During Application

The paint operator should follow the steps below to determine the weight (mass) of coating used during the application. This process begins by measuring the liquid coating, then uses the information to calculate the weight (mass) of the solid coating.

1. Prior to commencing the transfer efficiency test, appropriately label each part to be coated and then accurately weigh each part on the electronic balance. Record all of the weights.
2. Place the pressure pot or coating reservoir on the balance and slowly fill with coating, ensuring not to exceed the limit of the balance even after tightening the pressure pot cover.
3. Before commencing the actual test, apply the coating to several dummy parts to ensure that the coating application is representative of day-to-day production conditions.
4. To commence the test, disconnect the fluid and air hoses from the pressure pot. Do not allow any paint to drip to the floor as it is imperative that the coating fills the line all the way up to the spray gun. Record the coating weight and then replace the air and fluid hoses and commence the spraying operation.
5. For accurate results, continue spraying until at least 1 qt of the paint has been used (equivalent to approximately 2.2 lb or 1 kg). After applying the coating to the selected parts, immediately disconnect the fluid and air hoses from the pressure pot and record the second reading. Repeating this entire procedure at least three times can help in determining an average transfer efficiency at the end of the trials.

At any time during the test, take a small grab sample, approximately 1 pt of the coating, directly out of the pressure pot. Be sure to close the container to prevent solvent evaporation. Then send the sample to an analytical laboratory which will conduct a percent weight solids test in accordance with ASTM D2369. The ASTM D2369 is a standard test method for volatile coatings (1).

Do not bypass the sampling procedure by simply calling the coating manufacturer to request information on the percent weight solids or referring to the Material Safety Data Sheet (MSDS). Even a small discrepancy between the manufacturer’s value and the actual value obtained from the pressure pot sample will make a large difference to the transfer efficiency calculations.

The weight (mass) of solids used is calculated by the following equation:

$$\text{Wt. (mass) Solids Used} = \frac{\text{Wt. (mass) LiquidCoating* Percent Wt. Solids}}{100}$$

9.3.2.2 Determining the Weight or Mass of Solid Coating Deposited

As noted earlier, before starting the transfer efficiency test, each part was labeled and weighed. After applying the coating, it must thoroughly cure before weighing the part again. If the coating is normally air or force-dried, allow extra time for all of the solvent to evaporate. Curing the parts in an oven set at 230°F will result in a more accurate transfer efficiency reading, even if this is not the normal method for curing. This oven curing schedule is identical to what the laboratory will use to determine the percent weight solids of the one pint sample taken earlier during the test.

After the coating has thoroughly cured, weigh the parts. The difference between the weights of coated and uncoated parts represents the weight of solid coating deposited. Knowing the weight (mass) of solid coating used, and the weight or mass of solid coating deposited, calculate the transfer efficiency as follows:

$$\text{Transfer Efficiency} = \frac{\text{Mass solid coating deposited}}{\text{Mass solid coating used}}$$

9.3.2.3 Increasing Test Credibility

The credibility of the results depends entirely on the accuracy of all the weighings. If the factory has drafts or if vibrations from the floor affect the balance, the operator may wish to take two or three readings before recording any one weight. In addition, the laboratory determination of percent weight solids must be accurate. Finally, the accuracy of the results will increase if coating many parts during any one test, due to the larger sample size.

9.3.3 Using the Volume Method

The volume method is not as accurate as the weight method. Facilities reserve this method for parts that are too large or heavy to accurately weigh. For example, a facility operator might use the volume method to measure the transfer efficiency of a large transformer, street sweeper, forklift, engine block (which is too heavy but not too large for the balance).

When the object is large but has a relatively simple shape, a facility operator can often still use the weight method by “wallpapering” the surface with preweighed aluminum foil. At the conclusion of the test, weighing the dried coating on the foil completes the calculations.

To measure transfer efficiency using the volume method, a laboratory must determine the percent volume solids of the coating, as applied. To determine the volume of solid coating deposited, a lab measures the average film thickness of the deposited coating, as well as the total surface area of the coated parts.

9.4 The Effects of Common Spray Guns on Transfer Efficiency

The most important equipment to affect transfer efficiency, and thus pollution prevention, in a paint and coating facility is the spray gun. This section, therefore, describes available types of spray guns and discusses their effects on transfer efficiency.

9.4.1 Conventional Air Atomizing Spray Guns

These guns are still the most popular for providing high quality finishes on a wide variety of substrates. The spray guns work on the following principles.

The operator pumps fluid from a pressure pot to the spray gun under relatively low pressure, usually 10 to 20 psi. Sometimes, a cup contains the coating which is then siphoned directly to the gun.

The operator then feeds compressed air into the gun which mixes with the coating, finely atomizing it into very small particles. For most applications, the atomizing air pressure is 40 to 80 psi. One of the primary reasons for the gun’s popularity is that the operator can adjust both the atomizing air pressure and the fluid delivery rate because both controls are on the gun body itself.

Unfortunately, many operators set the atomizing air pressure considerably higher than what is necessary to produce an acceptable finish. For instance, while an air pressure of 40 psi may be adequate to produce the desired finish, the operator may choose to apply the coating at the maximum shop or line pressure of 80 psi or more. This, of course, can increase VOC emissions, waste, and clean-up efforts. Because of the high atomizing pressure, the finely divided spray particles form a fog in the spray booth. Moreover, as the particles travel at a relatively high speed from the gun to the target, the opportunity for the particles to bounce off the surface and rebound into the spray booth increases. Consequently, the transfer efficiency for this type of spray gun is usually fairly low relative to the other types. For this reason, the South Coast Air Quality Management District (SCAQMD), among other jurisdictions, have highly limited the conventional air atomizing gun. The actions of SCAQMD are important because the industry looks to SCAQMD to assess future regulatory trends regarding transfer efficiency and spray guns.

A general perception exists that the transfer efficiency for this gun is always low, perhaps around 25 percent. This is absolutely not so. When operators use the conventional air atomizing spray gun at low air pressures (less than 40 psi), transfer efficiency can be considerably higher than 25 percent, and, depending on part size, can even exceed 65 percent.

9.4.2 High Volume, Low Pressure Air Atomizing Spray Guns

The high volume, low pressure (HVLP) spray gun was introduced to the United States market in the mid-1980s. It is very similar to the conventional air atomizing gun. While the conventional gun atomizes the coating at pressures of 40 to 80 psi, HVLP guns use higher volumes of air at pressures less than 10 psi to perform the same function. Many regulations, such as those written by the South Coast Air Quality Management District, limit the air atomizing pressure to 10 psi to ensure the realization of transfer efficiency benefits from low air pressure.

Several methods are available for generating the high volume, low pressure air. During the mid-1980s the most common method was using a high speed turbine that draws large volumes of air directly from the surrounding space. The turbine pushes this high volume of air through a large diameter hose to the spray gun, but the air pressure can range from as low as 0.5 to 10 psi. The key to atomizing the coating with this method is the high volume of air that mixes with the coating inside the gun. In addition, the turbine tends to heat the air to a temperature of approximately 110^{o}F, which appears to benefit the application of the coating.

Historically, the turbine HVLP guns have been relatively expensive, with costs in the $2,000 to $15,000 range. More recently, spray gun vendors have introduced versions that do not require a turbine to generate the high volume air. Instead, they directly convert low volume, high pressure shop air, to high volume, low pressure by means of venturies or regulators. Typically, the incoming shop air is at 80 to 100 psi, while the air emerging from the cap of the spray gun is less than 10 psi. The volume of air for this gun is considerably less than that emerging from the turbine gun.

The major advantage of these newer pressure conversion guns is that they can immediately replace conventional air atomizing spray guns without requiring any other major capital purchases. The conversion units do not automatically heat the air as do the turbines, but several vendors provide in-line heaters with the option of heating the air if desired. Currently, all types of HVLP guns are popular, even if regulations do not require their use, because they have been marketed as high efficiency guns. Operators can use these guns to apply coatings to small, medium, and large targets. Some reports claim that the guns cannot keep up with high production-line speeds, but facilities must determine this on a case-by-case basis.

Generally, HVLP guns have been successful in atomizing a wide range of coatings, although some rheologies do not atomize well. Although the turbine-operated HVLP guns are more expensive than the pressure-conversion HVLP guns, the turbine types are generally more efficient at atomizing a wider range of coatings: therefore, in some cases, they are the most cost-effective option.

Transfer efficiency trials, which numerous companies and agencies have conducted, have demonstrated that the HVLP guns are generally more efficient than other gun types, and in some instances even more efficient than electrostatic spray guns. Each operating scenario determines how efficient one gun type will be relative to the other types. One should not be misled by advertisements which claim that HVLP guns are always more efficient than other gun types. Only on-line testing can provide the answer.

9.4.3 Airless Spray Systems

The airless spray system works much like a home water system. When turning on the faucet at home to take a shower, high pressure from the city's pumping station forces water through small orifices in the shower head. Depending on the size of the orifices, the spray is either fine or coarse.

With an airless spray system, a hydraulic pump siphons the coating out of a reservoir such as a 55-gallon drum, and then pumps the coating, usually under pressures of 1,000 to 3,000 psi, to the spray gun. The coating atomizes as it passes through the small orifice (0.011 to 0.074 inches) in the cap of the gun. The size and shape of the orifice determine the degree of atomization and the shape and width of the fan pattern. Moreover, a large orifice permits a higher fluid flow rate than a small orifice.

Unlike the conventional air atomizing spray gun, the airless spray gun does not permit the operator the same flexibility in setting spraying parameters. Further, because of the high fluid pressure, operators can apply large quantities of the coating relatively quickly. For this reason, operators often use the airless spray gun to apply coatings to large surfaces such as buildings, the sides of vessels in petroleum refineries, structures such as bridges, etc. In addition, operators often use this gun in coating facilities where the coating application must keep up with fast moving conveyors.

EPA has traditionally associated this gun with transfer efficiency values of approximately 40 percent but considerably higher values are obtainable. For instance, airless spray guns that coat large surfaces, such as large electrical control panels, railcars, ships, buildings, etc., are usually associated with much higher transfer efficiency values. Alternately, operators usually do not use this gun to coat small targets because the high fluid pressure tends to deflect small targets suspended on conveyor lines, and the generally high fluid delivery rates make it difficult to achieve acceptable-looking finishes. When using an airless spray gun to coat small targets, therefore, the operator can expect low transfer efficiencies, sometimes even lower than those which a conventional spray gun could achieve.

This gun has not been approved by agencies such as SCAQMD.

9.4.4 Air-Assisted Airless Spray Guns

The principle of this spray gun is very similar to that of the airless gun in that high fluid pressures force the coating through a small orifice in the spray gun cap.

The gun differs from the airless spray gun in that the fluid pressures are only 300 to 1,000 psi. These pressures, however, poorly atomize the top and bottom of the fan. Moreover, streaks or “tails” appear at the extremities. To eliminate the “tails,” low-pressure air emerges from separate orifices in the horns of the cap to force the “tails” back into the main portion of the pattern. The low-pressure air, 10 to 20 psi, does not atomize the coating particles, and therefore the gun differs considerably from the conventional air atomizing spray gun. The air-assisted airless gun is currently among the most popular types used in a wide range of industries. While it can handle relatively high fluid flow rates and therefore keep up with fast moving conveyor lines, it can also be adjusted for slow moving lines. Operators commonly use this gun to coat medium- and large-size targets, and in some cases to coat small parts, providing surprisingly appealing finishes.

EPA transfer efficiency table values which appear in various EPA documents, such as Control Technique *Guidelines, New Source Performance Standards (NSPS), National Emission Standards for Hazardous Air Pollutants,* are approximately 40 percent for the air-assisted airless spray gun. Agencies such as SCAQMD have not included this gun on their approved list of alternatives for meeting transfer efficiency requirements. This is partly because the operator can increase the air pressure to the horns of the gun to a point that compromises transfer efficiency. Some manufacturers have designed equipment that limits the shaping air pressure to a maximum of 10 psi. Some of the guns have been approved as meeting the definition HVLP.

9.4.5 Electrostatic Spray Guns

This category of spray guns embraces a wide range of technologies; electrostatic guns can use conventional air, airless, air-assisted airless, and HVLP atomizing technologies. The paint operator obviously has a wide range of spray gun designs from which to choose.

All of the electrostatic technologies have one thing in common: the gun imparts an electrostatic charge to the coating particles as they emerge from the spray gun nozzle. The operator must be sure to ground the target well so that the charged coating particles can seek the grounded part and deposit themselves on the substrate.

Operators and others commonly believe that when applying a coating electrostatically, the coating wraps around the target to coat not only the facing surface, but also the reverse side of the target. Advertisements and vendors’ literature reinforce this point. Unfortunately, here lies a misconception.

Some wrap of course takes place; the extent of the wrap, however, is often overstated. If coating round or square tubing electrostatically, the operator can expect almost total wrap around the entire tube because of the relatively small area that the coating must wrap. Alternately, when coating a medium or large flat target, the wrap only extends for approximately l/8 to l/4 inch around the reverse side. The wrap rapidly diminishes toward the center of the reverse surface.

Many parameters determine the efficiency with which the coating can wrap around the surface. These include:

- Polarity of the coating
- Voltage potential of the spray gun
- Air velocity in the spray booth
- Efficiency of the ground

The operator cannot assume that the target is always well grounded even if it attaches to a ground strap or suspends from a conveyor hook. In fact, significant electrical resistance can exist between the target and the ground. Poor wrap leads to a lower transfer efficiency. The mere fact that the spray pattern tends to bend toward the target when the paint particles follow the electrostatic field is already advantageous.

Most regulations that include a transfer efficiency requirement exempt electrostatic applications as being “deemed to comply.” Although some may infer from this that electrostatic applications automatically provide efficiencies of 65 percent or higher, such conclusions are false. Electrostatic applications do not automatically provide high transfer efficiencies, even if optimizing all the parameters. When compared with non-electrostatic applications, however, they usually show improved values.

By using the above information regarding spray gun options along with on-line testing, each facility must determine which pieces of equipment offer the best opportunities for increased transfer efficiency, and thus pollution prevention.

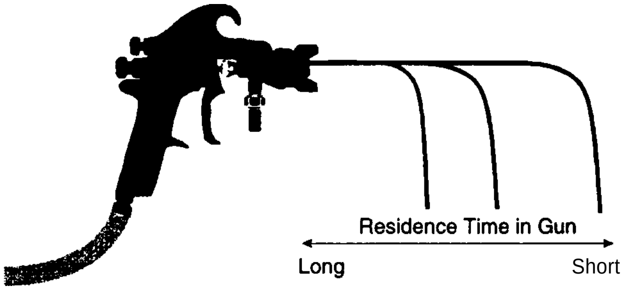
9.5 Pollution Prevention Strategies To Improve Transfer Efficiency

This section offers a broad range of strategies that facilities can use to improve transfer efficiency. Many of these can be implemented immediately, without the need for any capital expenditure or management approvals. Some strategies require minor modifications either to the spray equipment or to some other aspect of the painting process. Only a few require a moderate or significant expenditure.

9.5.1 Strategies That Require No Capital Expenditure

One of the most effective strategies for improving transfer efficiency calls for the spray painter to move closer to the part he or she is painting. A typical gun-target distance is 8 to 12 inches. In general, as the distance increases, transfer efficiency diminishes. As the distance decreases, however, the spray painter needs to reduce the fluid and/or air pressure to avoid applying too much coating to the target. This effective strategy requires only that the spray painter practice a new technique in applying the coating. The technique does not sacrifice production speeds nor does it involve important decision-making or expenditure considerations.

Another effective technique involves reducing the fluid flow rate. Figure 9-2 shows three different fluid flow rates measured by disconnecting the air hose from the spray gun. If the fluid pressure and corresponding fluid flow rate are high, the stream of paint emerging from the spray gun travels a relatively long distance before bending and falling to the ground. Such a flow rate has a very short residence time within the spray gun and requires a large amount of energy for proper atomization.



Strive for the lowest fluid flow rate that will do the job.

Figure 9-2. Effect of fluid flow rate on residence time in gun.

For instance, a conventional air atomizing spray gun requires a high air pressure to adequately break up the paint. As the fluid pressure decreases, the stream emerging from the spray gun shortens, and less energy is necessary to atomize it. Longer residence times lead to more efficient atomization, which in turn results in higher transfer efficiencies.

Many spray painters may argue that lowering the fluid delivery rate would slow down production speed and consequently raise the cost of painting. This argument is true for a very small percentage of coating facilities which have already optimized their fluid delivery rates to meet their production line speeds. By far, the majority of paint facilities do not measure fluid delivery rate nor correlate it with the production line speed. On the contrary, in most cases the fluid delivery rate is considerably greater than what the job requires; the majority of spray painters can lower their fluid pressures without impacting productivity.

When using a conventional air atomizing spray gun, HVLP gun, or any of the corresponding electrostatic guns, reducing the air pressure to accommodate the reduction in the fluid delivery rate results in a marked improvement in transfer efficiency. This translates into less air and waste pollution as well as less pollution associated with clean-up efforts. For the airless and in some cases also for the air-assisted airless guns, using a smaller orifice can achieve the same atomizing results. Once again, this strategy requires little or no expenditure, and in most cases can be implemented immediately.

Yet another effective method for increasing transfer efficiency optimizes the fan size to cater to the size of the part the operator is painting. Understandably, a spray painter would prefer to use a wide fan when painting large surfaces. The operator, however, must appropriately reduce fan size when painting smaller surfaces (see Figure 9-3). All too often, a spray painter uses a fan size of 6 to 8 inches to paint small- or narrow-shaped parts such as metal tubing or angle brackets. Adjusting the spray fan should not pose a major problem for spray painters who work on production lines that coat predominantly long runs of one part geometry. For those whose targets continuously change sizes, perhaps the best and most practical strategy is to purchase a cap enabling the operator to adjust the spray fan on the fly. Because not all spray guns can be fitted with adjustable caps, shop-

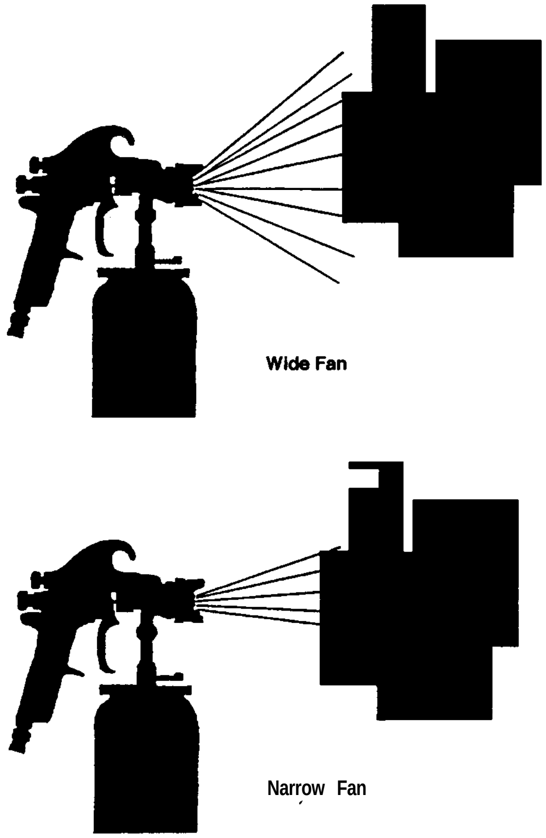
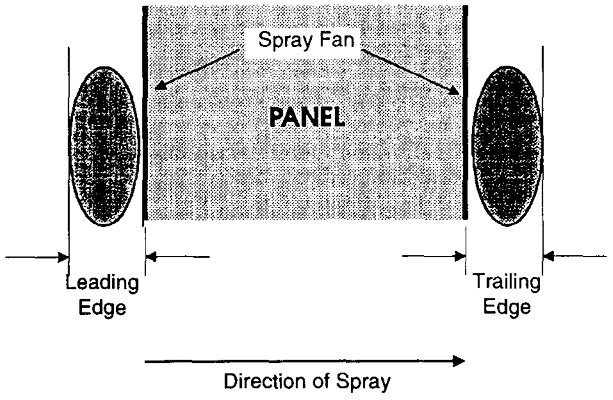


Figure 9-3. Effect of fan width.

ping around among equipment vendors for appropriate spray equipment may become necessary.

Finally, manipulating gun strokes can alter transfer efficiency. Specifically, minimizing the leading and trailing edges of gun strokes can significantly improve transfer efficiency. Figure 9-4 shows the concept of leading and trailing edges. On production lines that use reciprocators, the gun usually initiates triggering seconds before the target passes in front of it, and ceases triggering a few seconds after the target has passed. Where high quality appearance and uniform film thickness are mandatory, leading and trailing edges are necessary to prevent fat edges. In many cases, however, operators set the spray guns so that they trigger sooner than is necessary, or cease triggering too long after the part has passed. When painting small- or medium-sized parts, even a small decrease in the leading and trailing edge results in a significant improvement in transfer efficiency. Even when painting large parts, such as aircraft skins, this apparently small consideration can make a large difference to the resulting transfer efficiency. Further, a better transfer efficiency means less waste and, thus, less pollution.

Good Practice



Poor Practice

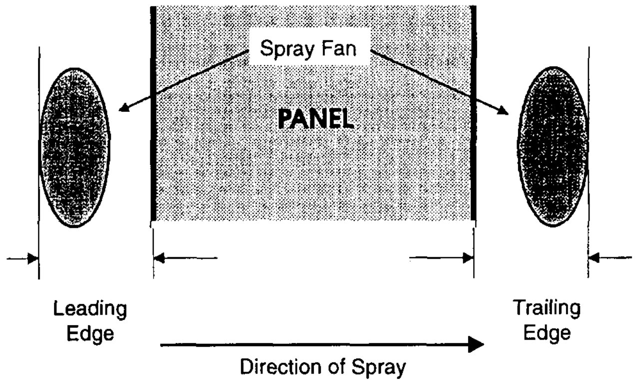


Figure 9-4. Effect of leading and trailing edges on transfer efficiency.

The strategy of minimizing leading and trailing edges also applies to using manual spray guns. Simply, the spray painter needs to learn to reduce the distance between the point of triggering and the edge of the target.

The concept of manipulating gun strokes also concerns the first and last stroke of a painting operation. For instance, suppose that a spray painter is applying a coating to a large flat panel, and that the fan on the spray gun is 8 inches. To ensure a uniform film thickness of the coating, the spray painter must apply the first stroke so that only the lower half of the fan passes over the panel while the upper half sprays into the air (see Figure 9-5). Then on the second stroke, the spray painter moves the gun down 4 inches so that the upper edge of the fan strikes the upper edge of the panel. For the third stroke, the spray painter moves the gun down another 4 inches and repeats the process. The 50 percent overlap between strokes helps to achieve a uniformly coated part. When the painter reaches the last stroke, only the upper half of the fan strikes the target, while the lower half sprays into the air. Unfortunately, the 50 percent overlap technique contributes to lower transfer efficiencies. To minimize this, however, the spray painter can use a reduced spray fan and ensure that the first stroke provides no more than 50 percent overlap. In too many cases, the spray painter applies the first stroke so that only 10 or 20 percent of the fan strikes the target. Facilities can implement this strategy immediately without the need for expenditure or management decisions.

9.5.2 Strategies That Require Nominal Capital Expenditure

Paint facilities equipped with conveyors often suspend their parts from hooks that are spaced at 18 or 24 inch centers. While it is appropriate to suspend medium and large sized parts from individual hooks, it is poor practice to do so when painting small parts or parts having a long and narrow shape, such as tubing or angle brackets. The most effective method for improving transfer efficiency entails suspending these parts from specially designed racks or hooks that allow for close spacing. Hook and rack manufacturers can provide catalogs with a wide range of products available off-the-shelf. These vendors also manufacture custom-designed hooks and racks for more complex-shaped parts. Not only does close spacing result in a significant increase in transfer efficiency, but it speeds up the production process, making it more efficient overall. Even though the purchase or manufacture of special racks may require capital expenditures, any medium-sized paint facility should realize the payback within a few months. When adding this benefit to that of minimizing pollution, the argument to invest in this equipment seems flawless.

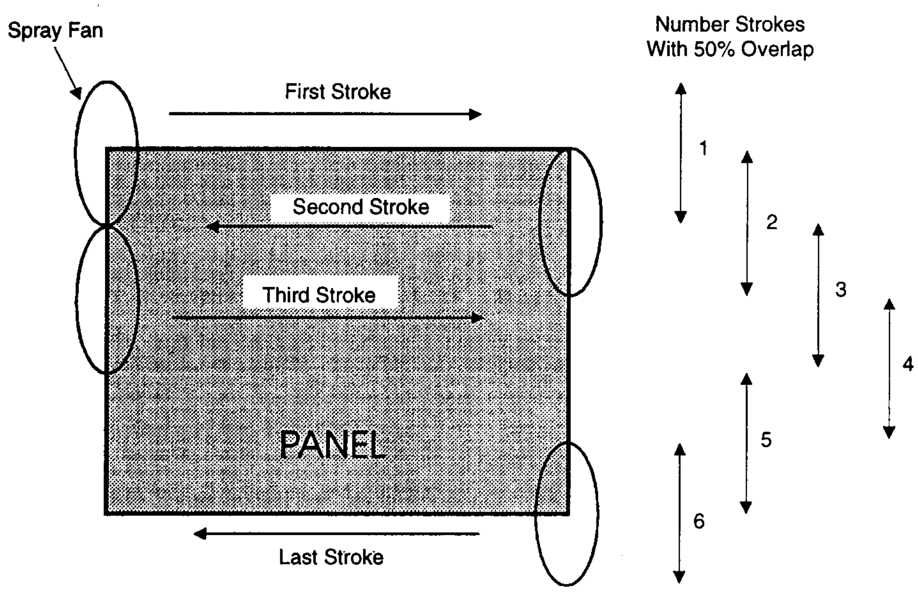


Figure 9-5. Deliberate overspray at top of first stroke and bottom of last stroke.

When operators paint small parts on pallets, the parts should be spaced as closely together as possible to maximize transfer efficiency.

Operators, however, cannot always achieve close spacing. For instance, painters can often not closely space complex-shaped parts that require painting from various angles without compromising finishing quality. Also, when using electrostatic spray guns, painters must provide sufficient spacing to allow for some wrap to take place.

Another obvious strategy for improving transfer efficiency and minimizing pollution is to apply the coatings with the most efficient spray guns applicable to the situation. Section 9.4 already discussed the benefits and limitations of most spray guns. Even though the purchase and installation of such equipment requires capital, facilities usually realize cost paybacks within several months.

A strategy often overlooked concerns the velocity of air passing through a spray booth. OSHA requires a minimum air velocity of 100 to 120 feet per minute through spray booths in which operators use manual spray guns. Alternately, OSHA allows facilities using automated electrostatic spray guns to lower their air velocities to 60 feet per minute. Many paint facility operators inadvertently run their booths at velocities well above these guidelines values because they are unaware of the deleterious effect this can have on transfer efficiency. On the other hand, some situations justify the higher velocities. When spray applying large volumes of polyurethanes or lead/chromate-containing paints, high air velocities minimize potential health risks to the painters. A few facilities must quickly remove overspray from the booth to prevent it from settling on freshly painted surfaces; these cases also require high air velocities.

High air velocities, however, are expensive. They add to electrical costs, and companies located in cold environments must also consider additional heating costs. Most facilities should reduce air flow rates, but not far exceed OSHA requirements. If overspray at the lower flow rates is high, painters should wear air-supplied respirators. Generally, painters who are accustomed to wearing such respirators enjoy them because of the clean and air-conditioned air that they supply. From the viewpoint of transfer efficiency and pollution prevention, lower air velocities through the spray booth allow the deposition of paint particles onto parts rather than into spray booth dry filters or water-wash curtains.

In situations requiring electrostatic spray guns, it is particularly important to lower the air velocity yet avoid violating any OSHA regulations. At high air velocities, the electrostatically charged paint particles do not have an opportunity to wrap the parts that they are intended to coat. Instead, the strong flowing air current pulls the particles into the booth.

Paint facilities that comprise several spray booths, all pulling from one air make-up system, may experience violently turbulent air velocities that change direction from one second to the next. In facilities such as these, it is not uncommon to see overspray blowing in the opposite direction from the spray booth filter bank or water-wash curtain. Often, an unusual amount of overspray deposited on spray booth ceilings and walls indicates turbulent air flow through the booth.

Because correcting turbulent air flow is often difficult, these cases may require air-conditioning or air-ventilation consultants to solve the problem. While this remedy costs money, the advantage to having a uniform, laminar air flow through a spray booth is improved transfer efficiency and significantly reduced overspray and booth maintenance. All these factors contribute to pollution prevention.

9.5.3 *Strategies That Require Moderate or Significant Expenditure*

Some paint facilities have such high VOC emissions that their state or local air pollution agencies require them to install abatement control equipment. The high cost of such an installation often justifies looking for alternative strategies to lower air emissions below the state's regulated threshold. If the strategies this chapter has already covered do not lower emissions sufficiently to preclude the use of abatement equipment, then a facility operator may need to consider more drastic measures. Alternative application methods such as dipping, flow coating, electrocoating, or powder coating, may resolve the emissions problems but the implementation of any of these methods requires many months of planning, testing, design, and of course implementation.

Despite the long lead time such a process change requires, and the costs associated with it, often this alternative is ultimately more cost effective than installing an abatement control device. Both choices result in the same goal-minimizing pollution.

9.6 References

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Chapter 10
Liquid Compliant Coating Technologies

10.1 Introduction

10.1.1 Pollution Prevention Considerations

The purpose of this chapter is to provide facility operators with guidelines for selecting coatings that reduce air, water, and/or waste pollution. Choosing the right coating constitutes one of the most basic decisions for an operator searching for ways to prevent pollution.

A liquid compliant, or VOC-compliant, coating is one that satisfies the VOC content requirements of the relevant regulation. The essential criterion for compliance is that the as applied coating satisfies the regulatory limit. For instance, a user who buys a packaged coating that just meets VOC content regulations cannot add thinner to that coating without rendering the as applied coating noncompliant.

Most facility operators probably already use low VOC coatings that meet the Reasonably Available Control Technology (RACT) limits of their state regulations, which is 3.5 lb/gal in many states. For users who still use VOC coatings that exceed the RACT limits, however, this chapter can hopefully provide them with means for choosing a technology that allows them to maximize reductions in the pollution of all media.

If coatings that go beyond RACT are not feasible, this chapter still provides end-users with suggestions for other process improvements that can at least lower hazardous waste and water discharges. In addition to lowering and preventing pollution, the guidelines this chapter presents should also lead to improved quality and lower costs.

The chapter first offers the reader guidelines for preparing to choose among the various options for specific applications. It then details the advantages and limitations of the specific technologies available, including a wide spectrum of water-borne and solvent-borne coatings. All these coatings are considered RACT, and some may be available in formulations that represent Best Available Control Technology (BACT). This discussion supplies the reader with the necessary information regarding how to choose a coating appropriate for the application while still reducing pollution. After a brief introduction to emerging technologies, the chapter concludes with tips for the selection process.

10.1.2 Decision-Making Criteria

Decision-making criteria relevant to liquid coatings, as addressed in this chapter, are highlighted in Table 10-l.

10.2 Guidelines for Choosing Best Management Practices

At the start of the resin system selection process, the end-user must tentatively choose between the following variables, keeping in mind pollution prevention, as well as quality and cost:

- Liquid versus powder coatings
- Water-borne versus high solids, solvent-borne coatings
- Air/force dry versus baked coatings
- Single-component versus two-component coatings

This section focuses on making these basic decisions. Section 10.3 helps to narrow the selection of coating still further.

10.2.7 Liquid Versus Powder Coatings

Someone approaching coatings for the first time, or willing to take a fresh look at the available options, must first decide on whether the coatings should be in liquid or powder form.

Because powder coatings are generally the lowest polluting of all coatings, they demand serious consideration. Powder coatings also offer attractive cost benefits and, in many instances, quality improvements. Powders are generally high performance coatings that provide excellent hardness, mar resistance, abrasion resistance, flexibility, elongation, UV resistance, and for some resins also chemical and solvent resistance. Liquid coatings, however, usually offer much more versatility in many areas.

Table 10-2 provides the most important advantages of liquid over powder coatings, while Table 10-3 provides the most important advantages of powder over liquid coatings.

Table 10-1. Decision-Making Criteria Regarding Liquid Compliant Coatings

Issue	Considerations
Instead of using a liquid coating, would a powder coating be a viable option to coat workpieces in question?	• If after referring to Chapter 11 of this text powder coating seems appropriate, consider using this as an alternative to liquid coating. • If powder coating appears inappropriate, use the remaining criteria to decide on the best liquid coating for the job.
Are the workpieces too large to fit into a baking oven?	• If yes, you must consider an air/force dried coating.
Are the workpieces small enough to fit into an oven yet cannot tolerate temperatures greater than 250^{o}F?	• If yes, you must consider an air/force dried coating.
Are the workpieces small enough to fit into a baking oven and do they require qualities such as hardness, abrasion and mar resistance, and some chemical resistance?	• If yes, you may consider either baked coatings or air/force dried thermoset coatings such as epoxies and polyurethanes.
Are the workpieces too large to fit into an oven but require hardness, abrasion and mar resistance, and some chemical resistance?	• If yes, consider air/force dried thermoset single- or two-component coatings such as epoxies and polyurethanes.
Are the workpieces too large to fit into an oven, but do not require hardness, abrasion and mar resistance, and some chemical resistance?	• If yes, consider a single component coating such as an alkyd or modified alkyd, which would be much less expensive than a two-component coating.
Is the location of the painting facility one in which operators commonly encounter low spray booth temperatures in the winter?	• If yes, solvent-borne coatings may be preferable to water-borne coatings.
Is the painting facility located in an area that commonly has high relative humidity (higher than 90%)?	• If yes, solvent-borne coatings may be preferable to water-borne coatings.
Does the coating require excellent chemical and solvent resistance, and also hardness, and abrasion and mar resistance?	• If yes, consider a solvent-borne epoxy primer followed by a single or two-component polyurethane topcoat: new water-borne polyurethanes might also be appropriate for wood products and may soon be available for plastic and metal. • If no, consider evaluating water-borne formulations.
Does the workpiece that requires hardness, abrasion resistance, chemical and solvent resistance, and exterior durability also lend itself to a dipping application?	• If yes, consider exploring autodeposited or electrodeposited coatings.

Table 10-2. Advantages of Liquid Over Powder Coatings

	Liquid	Powder
Part Versatility	More versatile for complex shaped parts.	Often not suitable for parts with many inaccessible areas and deep recesses.
Color Tinting	Colors can be tinted if vendor delivers wrong shade. Easy to color- match.	Cannot be tinted on the job. If wrong shade, the powder must be returned to vendor for blending.
Application Versatility	Wide range of application equipment allows flexibility in selecting appropriate equipment. This includes spray (many different types of spray guns), dip, flow, and curtain.	Not suitable for applications which can easily be dipped or flow coated. Possibly can compete with curtain coatings, but often film build will be too high. May not be suitable for very large parts such as weldments, although some large parts, such as pipe lines, are being powder coated.
Line Speed	Application equipment can keep up with very fast-moving production line.	Tribo-charging guns can apply coatings at faster line speeds than electrostatic guns, but for most very fast moving lines, liquid coatings may still be more cost-effective. This is especially true for complex shaped parts.

Table 10-2. Advantages of Liquid Over Powder Coatings (continued)

	Liquid	Powder
Substrate Versatility	Can be applied to all substrates: metals, plastics, wood, masonry, paper, cloth, etc.	For the most part, cannot be applied to most plastics, wood, paper, cloth, masonry, rubber, etc.
	Ideal for coating heat-sensitive substrates.	Not available for substrates that cannot withstand at least 250°F, and commonly 325°F and higher.
	Greater tolerance for "finger prints," small blemishes, and surface texture cleanliness.	Need cleaner substrates and sophisticated phosphate pretreatment system.
Application Temperature Versatility	Depending on the resin technology, can be applied at temperatures ranging from sub-zero to over 100°F	More commonly applied at ambient temperature. Generally is not applied at sub-zero temperatures, such as outdoors during winter months, or at high temperatures such as on heat stacks, etc.
End-use Temperature Versatility	Liquid coatings can be designed for low temperatures (sub-zero) to high temperatures (over 1,500°F).	Powders generally do not withstand excessively high temperatures, such as on high temperature exhaust stacks.
	Preferred for cryogenic applications.	
Resin Technology	Almost unlimited range of resin technologies available; resin system exists for almost any conceivable end use.	Although range of resin technologies is broad, it is not as broad as for liquids.
Finish Versatility	Usually can be formulated in any color, gloss level, and with a range of texture finishes.	May require more research effort to achieve equivalent results regarding color, gloss level, and texture finishes.
Environmental Conditions	Can withstand the severest of chemical environments, weather and atmospheric conditions (e.g., temperature, humidity, altitude), and marine conditions.	Generally not used in chemical plants, such as for tank linings, and are rarely used for severe marine exposure, such as on oil rigs. Due to a scarcity in performance histories relative to liquid coatings, end-user should perform extensive tests before using powder system.
		Powder coatings more sensitive to humidity and other atmospheric conditions due to fluidized bed of handling systems.
Curing Requirements	Ideal for large machines or assemblies that cannot be placed in a high temperature oven.	ReTire curing at temperatures in excess of 325°F. A few resins cure at a minimum of 250°F.
Applicability for Low Cost Items	Ideal for fence posts, some hardware building supplies, farm implements, etc., which are coated for appearance only, but require no other properties. Can tolerate minimal surface preparation.	Successful applications require certain process procedures, such as good surface preparation, coating thicknesses in excess of 1.0 mil, etc.; improved processes required would probably raise cost of low cost item so that it would no longer be competitive.
Masking Requirements	Because of the lower temperatures liquid coatings require to cure, masking is usually not a problem.	If the workpiece requires extensive masking, powder coatings may not be cost-effective.
Military Specifications	Nearly all military specification coatings are written for liquid coatings.	Although some military specifications have been written, and more will be issued, the majority are still for liquid systems.

Table 10-3. Advantages of Powder Over Liquid Coatings

	Powder	Liquid
VOC Emissions	Essentially zero VOCs	Usually at the RACT limits; some resin technologies are well below these limits, but are still well above zero VCC.
		Some coatings, such as UV curables are available at very low (almost zero) VOC levels, but have limited applications.
		Developing resin technologies will soon allow for zero VOC emissions; some are already available but for limited applications.

Table 10-3. Advantages of Powder Over Liquid Coatings (continued)

	Powder	Liquid
Hazardous Waste	Essentially zero hazardous waste; although some companies melt waste powder into solid blocks and then discard them as hazardous waste, volume is negligible when compared with similar liquid coating applications.	Disposal costs of waste liquid coatings far exceed those for waste powders; cannot totally eliminate hazardous waste.
Water Pollution	No water pollution due to powder coating application; always applied in booths containing dry filters or cartridges.	Cause a water pollution problem when they are applied in a water-wash spray booth.
Toxicity	Less toxic to operators because no solvents are used.	Water-borne are less toxic than solvent-borne coatings, but solvents are often used to clean up spray application equipment; some resins, such as polyisocyanates, are potentially toxic. Solvent-borne coatings are more toxic because of the solvents they contain; some resins, such as polyurethanes, may also be toxic.
Storage	Stored in boxes; do not need to be stored in explosion proof cabinets or storage sheds.	Water-borne coatings do not need to be stored in explosion proof cabinets, but often require more storage space than do powders. Solvent-borne coatings must be carefully stored in accordance with OSHA regulations.
Fire Risk	Lower fire hazard.	Water-borne coatings pose considerably less fire risk than solvent-bornes, but probably more so than powders.
Part Suitability	Ideal for flat parts and ones with relatively simple geometry; more cost-effective than liquid coatings for these items.	Liquid coatings can be used for same purposes, but not as cost effectively.
Clean-up Profile	Relatively clean process if spray booths operate under negative pressure. Most of the clean-up is usually carried out with compressed air or vacuum **hoses. No** solvents are used for clean-up.	Liquid coatings are undoubtedly more messy and require more clean-up (e.g., more rags, clean-up solvent). Usually some solvents are used to clean up residues of liquid coatings. For many facilities, the VOC emissions and hazardous waste from solvent clean-up operations is considerable. New aqueous technologies may change this trend.
Automation Suitability	Ideal for automated processes; reciprocators and robots can be used with relative ease.	Can be applied by automated processes, but requires more skill and effort to achieve acceptable finishes.
Learning/Training Requirements	Generally shorter learning curve for operators; while they must know about powder gun settings, voltage settings, etc., they do not need to be as knowledgeable as spray painters.	Painters need more training and a more rigorous learning curve; they must know how to apply coatings to achieve acceptable finishes, and about viscosity management, dealing with two-component coatings, and equipment clean-up; generally they need more knowledge about pressure settings, maintenance of pumps, spray guns, etc.
Labor Requirements	Because so many powder coating applications have some automation involved, less labor is usually required to apply coatings; often only a touch-up operator is required at end of powder coating booth.	Automation is used considerably less often than for powder coatings; liquid coating systems usually comprise at least two coats (primer and top coat), which requires more painters.
Transfer Efficiency	When specially designed powder coating spray booths are used, transfer efficiency can easily exceed 95% because the powder can be recycled. Equipment vendors are now improving spray guns to increase first pass transfer efficiency.	Usually, transfer efficiencies are well below 60% regardless of spray gun type.

Table 10-3. Advantages of Powder Over Liquid Coatings (continued)

	Powder	Liquid
Electrostatic Applications	Electrostatic powder applications are ideal for wire products because process transfer efficiency remains above 95%.	Liquid coatings can rarely be applied **as** efficiently to wire products. Electrostatic liquid applications are relatively inefficient. If they are spray applied, transfer efficiencies are often well below 20%. If they are dip applied, runs and drips often mar appearance of coated products.
	Ideal for parts with cut ends and sharp edges because one can often achieve higher film builds in these areas.	Liquid coatings can be applied with electrostatic spray equipment that helps to cover sharp ends and cut edges, but not as effectively as powder coatings. Where good corrosion resistance in these areas is mandatory, powders are superior.
Coating Profile	Requires just one coat application in most cases. A single coat of powder performs the same job as one coat of a liquid primer followed by a liquid top coat.	Rarely are liquid coatings applied as a single coat (usually only when color rather than corrosion resistance is required).
		A Naval Air specification calls for a single coat polyurethane, but this is applied over aluminum surfaces where corrosion resistance is better than for steel substrates.
	Generally more uniform thicknesses can be achieved.	Film thickness variation tends to be much greater with liquid coatings.

For readers who think powder coating may be appropriate, Chapter 11 provides more details about the powder coating process.

10.2.2 Water-Borne Versus Solvent-Borne Coatings

If powders do not constitute a feasible option, the next step should involve deciding between water-borne and solvent-borne coatings. Because most states require at the very least, RACT coatings, the discussion here on solvent-borne coatings only considers VOC-compliant, high solids formulations. (High solids, a loosely used term, most commonly indicates a solvent-borne coating with a solids volume of 52 percent or more.).

Tables 10-4 and 10-5 provide the most important advantages and limitations of each.

10.2.3 Air/Force Dry Versus Bake

Another important factor to consider is whether to pursue air/force dry coatings or select ones that bake at elevated temperatures, above 250^{o}F. Baked coatings usually have better physical and chemical-resistant properties but they also have some limitations. Table 10-6 provides some useful guidelines for each method.

Regarding the resin technologies that this chapter discusses, EPA and state regulations differentiate between coatings that air/force dry and ones that cure by baking.

EPA defines air/force dried coatings as those that dry or cure below 194°F and many rules establish special VOC limits for this category. In contrast, coatings that cure above 194°F are often regulated as “baked” coatings and must follow lower VOC limits. Mostly, the limits for the air/force dry category are higher than for the baked. For example, Table 10-7 lists the regulations guiding the coatings used in the Miscellaneous Metal Parts industries.

10.2.4 Single-Component Versus Plural-Component

Finally, another important basic factor to consider involves whether to select a single-component or plural-component technology. Generally, plural-component coatings have much better physical and chemical resistant properties. This superiority, however, does not come without drawbacks. Single-component coatings are much easier and less expensive to use. They also are usually associated with a better pollution prevention profile. The most important differences between the two technologies are presented in Table 10-8.

10.2.4.1 Plural-Component Coatings

Because the handling of plural-component coatings is more complicated and because they are associated with more hazardous waste than single-component coatings, plural-component coatings require a more detailed discussion. Usually, a plural-component coating comprises two components. Occasionally, however, it comprises three components, one of which may be a thinner or chemical.

The largest source of hazardous waste generated by companies using plural-component coatings comes from batch mixing processes. While such mixing is

Table 10-4. Advantages of Water-Borne Over High Solids Solvent-Borne Coatings

	Water-Borne Coatings	High Solids Solvent-Borne Coatings
VOC Emissions	Usually meet air pollution regulations.	These coatings often just meet the RACT limits. They usually are not available at the typical VOCs of some of the water-borne formulations.
	Some coatings have very low VOC contents, well below RACT limits, and help lower total emissions from the facility.	
	New developments are tending toward zero VOC formulations, but don't yet have any reliable performance history.	New 100% solids coatings are being introduced, but they require baking at elevated temperatures, such as 250° to 350°F. Moreover, they are too new to have a performance history.
Drying Factors	Some air/force dry, single-component formulations, particularly some emulsions, dry considerably faster than high solids solvent-borne coatings. Others, however, dry slower than solvent-bornes. The end-user should obtain such data from the coating vendor or should perform in-house tests to ensure that the drying time is compatible with existing production conditions.	Many of the air/force dry, single-component high solids coatings, such as alkyds and modified alkyds take a relatively long time to dry. This is even more noticeable with excessive film thickness.
	Oven drying at temperatures below 194°F. and/or moving air over the workpiece enhances drying.	Oven drying at temperatures below 194°F enhances drying but moving air over the part offers little benefit because solvent evaporation is not affected by relative humidity in the air.
Film Thickness	Relatively low volume solids contents, usually 25-30%, make it possible to apply coatings at low film builds, approximately 0.8 - 1.0 mil. This can be a major advantage of water-borne over high solids.	Unless high solids coatings have low viscosities, most application equipment cannot atomize these formulations well enough to provide low film builds.
		At difficult to reach areas, or when coating a complex-shaped workpiece, excessive film thicknesses are often unavoidable. This results in higher than anticipated VOC emissions, longer drying times, longer recoating times, higher reject rates due to premature damage, and increased coating usage. Using polyurethanes, however, may minimize these problems.
Safety Profile	Water-borne coatings are generally safer to work with than solvent-borne coatings: low fire hazard, less of a requirement for explosion proof storage areas, and less toxic to operators.	Solvents pose a fire risk.
		Also, solvents can potentially cause health problems for operators. Regardless of what type of coating is used, water- or solvent-borne, painters must wear the appropriate respirators and if necessary other apparel.
Dip Coating	Water-bornes are ideal for dip coating application, particularly if surface preparation is adequate.	High solids coatings cannot be used in dip tanks because their viscosity is too high, and runs and sags become a major finishing problem. Moreover, at the high film thicknesses deposited, the coatings would take too long to dry.
Appearance Defects	Appearance defects such as orange peel, solvent popping, and non-uniform color and gloss usually do not pose a major problem.	Because of the generally high viscosities of these coatings, defects such as orange peel and solvent popping can become major factors affecting the reject rate.
		On complex-shaped workpieces, where non-uniform film thicknesses can lead to variations in color and gloss, customer rejects can also be a problem.

usually more cost-effective when using small quantities of coatings, using plural-component metering and mixing equipment is better for large quantities.

Consider the following example. An operator can batch mix components A and B by manually mixing immediately before applying the coating. The operator must be sure to use all the coating before its viscosity changes and it reaches its pot-life. This may be difficult to do if the operator has mixed a large quantity.

Alternatively, the operator can set special proportioning equipment to automatically measure out each component in its prescribed ratios. This is called in-line mixing. The equipment continuously pumps each component separately to a manifold where they come together in

Table 10-5. Advantages of High Solids Solvent-Borne Coatings Over Water-Borne Coatings

	High Solids Solvent-Borne Coatings	Water-Borne Coatings
Application Flexibility	Solvent-borne resin technologies are available for almost every conceivable application.	While water-borne coatings are able to match many types of solvent-borne coating, they are not yet as versatile.
Surface Preparation	Traditionally, low solids, high VOC solvent-borne coatings have been tolerant of improper surface preparation. Newer high solids coatings require cleaner surfaces. Even these, however, remain more tolerant to surface preparation than their water-borne counterparts.	Coatings are sensitive to surface preparation; therefore better cleanliness is required. As water-borne technologies with lower, or zero VOCs are developed, the need for better surface preparation will probably become mandatory. This need for cleaner surfaces can be a major factor for companies with marginally acceptable pretreatment lines.
Appearance Defects	High Solids coatings are not as sensitive to defects such as edge pull, and cratering as are water-bornes.	Water-bornes must be applied correctly to avoid problems such as edge pull and cratering. This requires good viscosity management and quality control procedures. Flash rusting with some formulations can be a problem. This can be overcome by properly formulating the coating, and if the vendor's requirements for surface preparation have been met.
Viscosity Management	In many cases, viscosity management is easier for solvent-borne coatings than for water-borne.	Some water-borne coatings are significantly thixotropic, and are not easy to apply by untrained painters. After the painters have been trained, usually by the vendor, this problem no longer is an issue.
Electrostatic Application	Grounding for electrostatic applications is usually not a major problem. If the coating is not sufficiently conductive, the vendor can often modify the solvent blend so that the coating can accept an electrostatic charge.	For water-borne, grounding and electrical isolation can be a major problem, particularly in large facilities which pump coatings over long distances, or pump from 55-gallon drums or totes. New equipment technologies, however, are available which can essentially eliminate these problems. The end-user should discuss this issue with equipment vendors.

the fluid hose leading to the spray gun. Downstream of the manifold is a short static mixer, which comprises a short plastic or stainless steel tube located in the fluid hose only a few inches or feet from the spray gun. Small baffles in the tube thoroughly mix the components immediately before they enter the spray gun. In-line mixing allows for components A and B to be mixed on a continuous basis. The primary advantage of this process is that the viscosity of the coating remains constant throughout the day, and the coating is used before it can attain its pot-life.

What constitutes a small or large quantity? A rule of thumb is to use a batch mixing process when mixing and applying less than 2 to 3 gallons of plural-component coating in one shift, particularly if there is a color change between jobs. Because batch mixing requires more solvent for clean-up and generates more waste compared with a plural-component system, it is not a good choice for large quantities.

Plural-component metering and mixing becomes cost effective when using several gallons of plural-component coating at any one time, particularly if a color change is not required. If operators will continue the job on the following shift or the next day, only the fluid passages that contain the mixed coating need cleaning. Fluid lines and passages that carry unmixed component A or B do not need cleaning because the coating will not cure in the absence of the other component. Companies such as automotive original equipment manufacturers (OEMs) can justify the use of plural-component equipment even when changing colors frequently. This is because only the short whip hose that contains the mixed coating requires flushing. (Spray equipment vendors provide sophisticated devices for enabling quick color changes.) Hence, for large facilities the cost of installing such equipment is often quickly offset by the savings in waste paint and disposal of hazardous waste.

Some companies cannot justify the purchase and installation of plural-component metering and mixing equipment and must practice batch mixing. They can, however, dramatically cut costs of materials and waste by ensuring that painters mix only as much coating as the job on hand requires. This conservative method also

Table 10-6. Air/Force Dry Versus Bake

	Air/Force Dry	Bake
Substrate Versatility	Can be applied to all substrates (e.g., metal, plastics, wood, rubber, masonry, etc.).	Can only be applied to metals and substrates that can withstand high baking temperatures. Generally not suitable for heat-sensitive materials such as plastics, wood, rubber, hydraulic tubing, etc. Should not be applied over machined or other surfaces that are sensitive to warpage, unless taking adequate precautions.
	Can be applied over porous materials such as sand castings, wood, paper, etc.	Can cause outgassing on sand castings and other porous substrates. Preheating workpiece can often overcome problem but adds an additional step to process.
RACT Regulations	Some regulations have higher VOC limits for air/force-dry than for bake coatings.	Same
Heating Requirements	Can dry and cure at temperatures from ambient up to 194°F by EPA definition. Solvent-borne coatings do not require an oven, although a low temperature oven will speed up the drying process. Water-borne coatings would benefit from a low temperature oven, particularly in high humidity environments.	Generally must cure at a minimum of 250°F. A typical curing schedule is 10 minutes @ 350°F. Curing times are inversely proportional to temperature. A cool-down staging area is required.
	Offers lower energy usage.	Require high-temperature oven, and therefore greater energy usage.
Physical/Chemical Properties	Most single-component coatings, such as alkyds and modified alkyds, do not exhibit superior physical and chemical properties. Single-component moisture-cured polyurethane, however, do perform comparably to two-component polyurethanes and baked coatings.	Often have excellent physical and chemical-resistant properties, sometimes similar to two-component polyurethanes.
Appearance Defects	Surface defects, such as orange peel, often do not flow out during the drying and curing process. Force-drying at elevated temperatures, but below 194°F, can partially alleviate this.	Films tend to flow out better when in the oven, providing smooth finishes and eliminating surface defects such as orange peel.
Curing Time	Take longer to achieve through hardness, which can affect production schedules.	After baking and cool-down, the coated parts are usually ready for assembly or shipping.
Clean-up Requirements	Overspray dries on spray booth filters, spray booth floors, walls, etc.; therefore, maintenance is not a significant problem.	Uncured overspray remains sticky, making it awkward to walk on spray booth floors. Maintenance is more costly because of difficulty handling the sticky material.

Table 10-7. Typical RACT Limits for Miscellaneous Metal Parts Coatings

	Air/Force Dry		Bake	
	lb/gal	g/L	lb/gal	g/L
California	2.8	340	2.3	275
Most other states	3.5	420	3.0	360

allows painters to use all the coating before it reaches its pot-life.

In facilities that use 1 to 3 gallons per shift, painters often find that the mixed coating reaches its pot-life before the job is complete. Strategies some facilities use for extending the pot-life are:

- Mix smaller quantities
- Cool the coating
- Add more freshly mixed coating
- Add solvent (not recommended)

The best of these options is to mix smaller quantities, all of which painters can fully use before the pot-life is reached. This option is associated with the least waste and the least risk. The remaining three options should be discouraged because they have too many drawbacks.

Cooling the coating is a viable option because it slows the cross-linking reaction. This practice requires caution because if the coating chills below the dew point of the ambient air, condensation of moisture can cause gel particles of cured coating to form inside the coating. These cannot be easily removed, not even by passing the coating through a fine mesh screen or filter.

Table 10-8. Single-Component Versus Plural-Component Coatings

	Single-Component Coatings (Such as Alkyds)	Plural-Component Coatings (Such as Polyurethanes)
Hazardous Waste Considerations	Generally result in considerably less hazardous waste; whatever has been mixed and cannot be used, can be saved for another day.	More hazardous waste is generated, particularly if the two components are batch mixed.
Training Requirements	Painters need not go through any specialized training program.	Painters must be trained to properly mix and handle two-component coatings.
Mixing Requirements	Require no special mixing instructions.	Must be precisely mixed in the proportions vendor recommends. Failure to do so can lead to improperly cured coatings, rejects, and generation of more unnecessary air, water, and waste pollution.
Induction Times	Require no induction times. The coatings can be applied immediately.	May require induction time of up to 30 minutes (primarily for some epoxies).
Pot Life	There are no pot life considerations.	Always have a limited pot life, and the mixed coating must be used within that period.
Viscosity	Because cross-linking does not take place until the coating has been applied, viscosity remains constant throughout the day (at constant temperature).	Viscosity of the mixed coating increases with time while the polymers cross-link.
Cleaning Considerations	Spray hoses do not need flushing out as frequently. Large facilities that apply the same coating each day infrequently clean the hoses.	If the coating has already been mixed, spray hoses must be flushed before the coating has an opportunity to gel.
Physical Properties	Generally form softer and less abrasion-resistant films. This can lead to a higher reject rate due to early damage. As the reject rate increases, so do costs and pollution.	Known for their superior physical properties. Many companies have invested in two-component coatings specifically to reduce reject rate.
Chemical Properties	Generally fewer chemical- and solvent-resistant properties.	Known for their superior chemical-resistant properties.
Cost Considerations	Generally, cost per gallon is considerably less than for two-component coatings. Costs can vary from a low of less than $10 per gallon to a high of $30 per gallon.	Usually more expensive than single-component products. Costs can vary from a low of $25 per gallon to a high of well over $100 per gallon. Some exotic-colored automotive refinishing colors can exceed $150 per gallon.
	Maintenance costs are usually less because coatings do not harden as quickly in fluid passages and are easier on pumps and spray guns.	Cost of replacement hoses, pumps, and spray guns will increase because occasionally the coating hardens before painters have had a chance to clean fluid passages.

An operator must never add one component without the correct proportion of the other. Complete cross-linking can only occur when both components are present in their stoichiometric proportions. Stoichiometric proportions imply that components A and B have the same total number of functional groups. Paint chemists formulate coatings to allow for simple mixing ratios, such as 1:1, 2:1, 4:1, etc. For instance, if only component A is added to extend the pot-life, the cured coating may tend to remain soft and cheesy, and will lose much of its chemical- and solvent-resistant properties. On the other hand, if adding only component B, the cured coating may be too hard and brittle, and will tend to crack and spall from the surface.

Finally, facilities should strongly condemn adding solvent to extend pot-life, even though it is a popular method. Adding solvent carries with it a great possibility that the VOC content of the mixture will exceed the regulated limit, exposing the company to a possible Notice of Violation. Worse than this, however, the solvent is added to a coating that has already started to polymerize. While the painter may be satisfied with the finish of the applied coating, the coating may harden and cure before all of the solvent has had an opportunity to evaporate out of the film. The entrapped solvent might gradually migrate to the coating/substrate interface, loosening the adhesive bond between the primer and the substrate. Catastrophic coating delamination can occur, which may only become evident months or perhaps years after the finished product has been in service.

10.3 Water-Borne Coatings

10.3.1 Overview

The term “water-borne” describes coatings in which the predominant solvent is water. Organic solvents (VOCs) are also used but, for the most part, their concentration is small. In many formulations the ratio between the amount of water and organic solvent is 80:20.

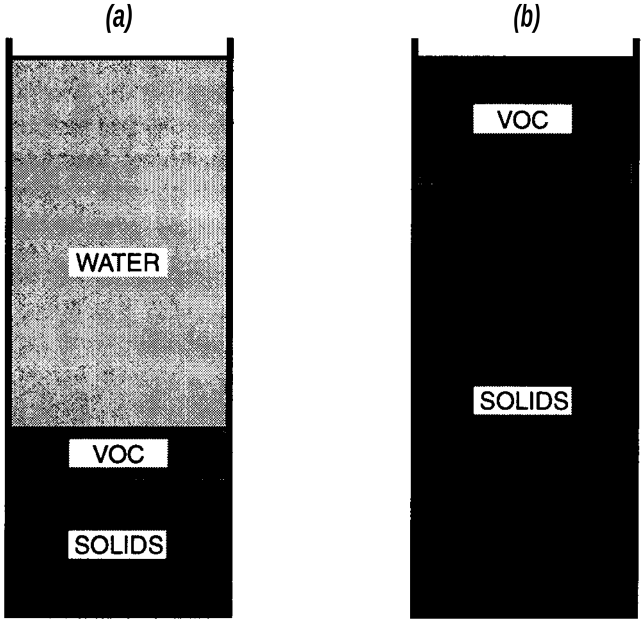
The organic solvents, often referred to as co-solvents, enhance the formation of the coating film, especially during the drying process when the water is evaporating from the deposited coating. As resin manufacturers develop new resin technologies, they are reducing the amount of co-solvent required to form the film. Currently, new formulations exist that contain no co-solvents, and consequently have zero VOC. Although this chapter will cover these, they do not yet have a long-term performance history; therefore, most end-users will probably consider the more conventional water-borne coatings.

The term “water-borne” includes water-reducibles, emulsions (latexes), and dispersions. Most vendor data sheets do not make any distinction between the three types. Because the end-user does not need to know the differences between these types in order to select an appropriate coating, this chapter does not cover the distinctions.

Most VOC regulations limit the VOC content of a coating in terms of pounds per gallon or grams per liter, less water and less exempt solvent. Because exempt solvents, such as methylene chloride and I,I,I trichloroethane are being phased out, this chapter does not address resin technologies that rely on these solvents for compliance.

When dealing with water-borne coatings, the end-user must thoroughly understand the terminology most regulations use. For instance, 1.0 gallon of a water-borne coating contains many ingredients: the resin (or binder), pigments, extender pigments, coalescing agents, a small quantity of co-solvents, and usually a fairly substantial amount of water. The volatile portion of the coating comprises the co-solvents and water. In a gallon can, the co-solvents, which are considered to be the VOCs, may account for less than 1.0 pound.- In other words, the VOC content of the coating may only be 1.0 pound/gallon. The VOC regulations, however, require that the VOC content of the coating be calculated as if no water were in the coating. Depending on the coating formulation, the VOC content, less water, may be considerably higher, such as 2.0 pounds/gallon or more.

Figure 10-l a illustrates what 1.0 gallon of water-borne coating might look like if separating the ingredients into discrete layers. Clearly, the amount of VOC in the can would be very small, especially when compared with the amount of water. If water were removed from the can so that the coating only comprised the VOC and solids portions, and if the can were then filled to the gallon mark, the contents would resemble Figure 10-1 b. When EPA and state regulations specify a VOC content less water, they refer to the VOC content represented in Figure lo-lb.



Including water

Excluding water

Figure 10-1. VOCs in water-borne coatings.

In order to understand the rationale for this approach, remember that in applying a coating, one is interested only in the amount of solid that a substrate needs deposited. For instance, when applying a red enamel over a yellow primer, a painter uses only as much coating as will completely hide the underlying color. For many coatings, a dry film thickness of 1 mil (0.001 inch) may suffice. It does not matter if the coating is water-borne or solvent-borne; the only consideration is depositing the specified dry film thickness of solid coating. Assuming that the composition of the solid ingredients is the same in both coatings of Figure 10-1, a painter would deposit exactly the same amount of solid coating in each case. The only difference between the two figures is the lack of water from the second figure. Because the gallon can in Figure 10-1a has less solids than that in Figure Io-lb, a painter would use a greater volume of the Figure 10-1 a coating to deposit the same amount of solid coating as he would to apply the coating in Figure lo-lb.

Note that the ratio of VOC to solid in Figure 10-1a is the same as the ratio of VOC to solid in Figure 10-lb. In summary, regardless of which paint can (Figure 10-1a orb) a painter uses to coat a substrate, the same volume of solids will be applied, thus emitting the same amount of VOCs to do the job.

10.3.2 Water-Borne Air/Force Dry Alkyds, Acrylics, Acrylic-Epoxy Hybrids

Probably the most common water-borne coatings for metals, air- or force-dry at temperatures below 194°F. A wide range of coating formulations fall into this broad category. The most commonly available technologies are water-borne alkyds and modified alkyds, acrylic latexes, and acrylic epoxy hybrids. Often, consumers are unaware of which of these technologies they are purchasing because manufacturers frequently sell the coatings as generic water-borne products. A brief description of the basic differences follows.

Water-reducible, or water-thinnable, alkyds and modified alkyds are similar to the solvent-borne alkyds with which most companies are familiar. Like the solvent-borne coatings, they are modified polyesters but have high acid values and employ special chemical blocking agents such as carboxylic acid functionalities. When the alkyds are neutralized with ammonia or volatile amines, it is possible to use water as the reducing liquid. Although they may take longer to dry, the resulting coatings have gloss, flow, and leveling properties similar to their solvent-borne counterparts.

The acrylic latexes include other polymers such as vinyl acrylic and styrene acrylic. The resins are high molecular weight polymers dispersed as discrete particles in water. Those formed by polymerizing a single monomer are called homopolymers, while those polymerized from a blend of two or more different monomers are called copolymers. Most of the latexes used to coat miscellaneous metal parts and architectural substrates are copolymers.

Latex coatings do not undergo a chemical change as they dry. The basic latex polymer and specific modifications are responsible for the characteristics of hardness, flexibility, chemical resistance, abrasion resistance, and physical and chemical attributes. Acrylic latexes are known for their good exterior durability and excellent resistance to ultraviolet (UV) degradation. In outdoor exposure, they retain their original gloss and color over long periods. In this regard, they are superior to unmodified alkyds, which tend have poorer gloss and color retention.

Manufacturers specify acrylic epoxy hybrids even less commonly than the other water-borne products. These hybrids comprise two- or three-package systems in which emulsified epoxies cross-link with aqueous acrylics. Properly formulated coatings are corrosion resistant and can produce finishes that have very good gloss, hardness, alkali, and abrasion resistance. Unlike conventional solvent-based epoxies, some mixed water-borne coatings have pot-lives of up to 36 hours at reasonable ambient temperatures. End-users prefer acrylic epoxy hybrids for applications that require hardness, flexibility, and chemical resistance.

10.3.2.1 Advantages

As a generic group, water-reducible formulations, dispersions, and emulsions are ideal for companies that still need to comply with VOC regulations yet do not require their coatings have sophisticated properties. As a group, the water-bornes tend to have VOC contents well below 2.0 lb/gal (240 g/L), less water, and some are even below 1.5 lb/gal (180 g/L). Actual VOCs including water are usually below 1.25 lb/gal (150 g/L), and this makes them an ideal choice for companies that have a need to dramatically reduce their VOC emissions.

Generally, they exhibit good performance properties, but are probably not as durable or chemical- and solvent-resistant as two-component polyurethanes, epoxies, or baked finishes. Facilities would consider them for applications such as dipping primers and topcoats, general purpose shop primers, and spray applied enamels. They are suitable for coating steel, aluminum, galvanizing, plastic, wood, and architectural substrates. In addition, they are available in a wide range of colors and gloss levels.

Typical end-uses include steel roof trusses, steel building support structures, farm implements (not combines or tractors), electrical cabinets, boxes, frames, fence posts, and similar general metal products. The electronics and business machines industries currently use them to coat plastic computer housings, keyboards, and similar items. The architectural industry uses these coatings for interior and exterior walls, ceilings, concrete bridge structures, and other commonly used masonry surfaces. In the industrial maintenance industry, water-bornes can be used to coat items such as steel structures and hand rails provided that there is no exposure to chemical and solvent fumes or liquids. The coatings formulated for architectural end-use differ from those formulated for industrial use. The latter are designed to provide metal parts with corrosion resistance.

These water-borne coatings have a host of other advantages associated with their actual application. They can be spray-applied with standard equipment. In addition, they can be touched-up with self (i.e., with the very same coating). And like their solvent-borne counterparts, they are available in a wide range of texture finishes.

Water-borne coatings also have safety and pollution-prevention advantages. Because of their high water content they pose a low fire hazard. Moreover, they generally have lower toxicity because of the reduced concentration of organic solvents.

Unlike solvent-borne coatings, operators can flush water-bornes from spray hoses with tap water. The usual procedure for cleaning the hoses is to flush with water, follow with solvent, and follow again with water. The small amount of solvent is necessary to clean out dried or non-water-soluble coating residues from the inside surfaces of the fluid hose.

10.3.2.2 Limitations

Most of the limitations associated with these water-borne coatings relate to their performance. Compared with 2-part polyurethanes or baking water-reducibles, they have poorer exterior durability and poorer resistance to salt spray, humidity, chemicals, and solvents.

In general, the coatings do not meet standards for high performance in industries such as heavy-duty maintenance, aerospace, appliance, and automotive. In addition, many formulations require a greater learning curve with regard to viscosity management compared with other compliant coatings.

When applying the coatings in humid or cold environments, it is important for operators to force-dry them at a low oven temperature of approximately 120^o to 150°F. If no oven is available, consider blowing air over the parts to promote the evaporation of water from the coating film. Omitting this step can lead to a poor quality film, initially resulting in handling damage and possibly the early onset of corrosion and other premature failures.

Although the lower concentrations of solvents in their formulations benefit pollution prevention, this also causes these coatings to be more sensitive to substrate cleanliness than most solvent-borne coatings. Similarly, the clean-up process these coatings require also reduces pollution, as described earlier. Unlike solvent-borne coatings, however, operators must factor in a three-step process: water, solvent, water.

10.3.3 Water-Borne Epoxy Water-Reducible Air/Force Dried Coatings

Water-borne epoxy water-reducible air/force dried coatings have been available since the early 1980s and have a proven history of performance. These high performance coatings most often are used as air/force dry coatings, where they can be cured at room temperature, or below 194°F. Although many data sheets show they are available at 2.8 lb/gal (340 g/L), less water, newer formulations are approximately 10 percent lower. They provide a viable choice for companies wanting to significantly lower their VOC emissions without compromising performance.

Manufacturers supply these coatings as two- or three-package systems. The most commonly available water-reducible epoxies are formulated as primers complying with military specifications MIL-P-53030 (lead- and chromate-free) and MIL-P-85582 (containing chromates). Facilities can topcoat them with most other coating systems, such as polyurethanes, particularly when requiring good corrosion resistance. Companies that do not need to comply with military specifications can also consider using these coatings because they are compatible with nonspecification topcoats. As with all high performance coatings, properly prepared surfaces are mandatory.

Because epoxies tend to chalk when exposed to weather and sunlight, they usually do not serve as outdoor topcoats. For interior exposure, however, such as the internal linings of steel pipes and vessels, pumps, and laboratory equipment, they can serve as both primers and topcoats. As primers, they are commonly specified for steel weldments, such as automotive chassis, cabs, truck bodies, military hardware, steel and aluminum frames, cold rolled steel panels and cabinets, aerospace components, and electronic components.

An end-user should not implement this technology until after performing extensive on-line testing to ensure that the product is compatible with production and performance requirements.

10.3.3.1 Advantages

The first advantage to note regarding these coatings relates to pollution prevention. The VOC is below the RACT limit for all states, including California. This group of coatings serves as an ideal choice for a high performance primer when emission reductions are important. The VOC content is below 2.8 lb/gal (340 g/L), less water, for the mixed product, and is approximately 1.5 lb/gal (180 g/L), including water.

These coatings also offer a range of choices. Primers are available in both chromate and non-chromate formulations. The chromate-containing products offer improved corrosion resistance compared with the nonchromate products. The aerospace industry, for the most part, prefers to specify chromates, even though they are more toxic than the nonchromates and contribute to liquid and solid hazardous waste. This preference derives from chromates' improved corrosion-resistant properties, particularly with regard to filiform corrosion. The Naval Air Systems Command has written MIL-P-85582 to describe this formulation.

When applied to aluminum substrates, or zinc phosphated steel, the nonchromate formulations apparently also perform very well, although they are not recommended when filiform corrosion cannot be tolerated. The army has approved such formulations, and has written MIL-P-53030 to cover them.

Water-borne epoxy water-reducible air/force dried coatings dry quickly, even in highly humid environments provided good ventilation exists. This means that recoating with a polyurethane topcoat can take place as soon as the water evaporates out of the film. Some facilities have followed intercoating time intervals of as short as 30 minutes, although this is not considered to be good general practice. These primers are compatible with many types of topcoats, especially water-borne or solvent-borne polyurethanes. They are also compatible with solvent-borne epoxy coatings.

Finally, these coatings have favorable viscosity properties. Although they have a limited pot-life, usually 6 to 8 hours or more, they retain low application viscosities for a longer time than most low-VOC, high solids, solvent-borne plural-component coatings. Also, because of their low application viscosity, usually less than 20 seconds on a Zahn #2 cup, operators can apply them with all types of spray equipment, including conventional spray, HVLP, and electrostatic spray guns. The low application viscosities allow operators to apply the coating in dry film thicknesses of 1.0 mil or less. This can be an advantage over high solids, solvent-borne epoxies for which such low film thicknesses are often difficult to achieve. In addition, these coatings can be mixed with plural component metering and mixing equipment, but the end-user must first conduct tests to confirm that the viscosities prior to mixing are not so high that they cause a materials handling problem.

10.3.3.2 Limitations

The most important limitation associated with water-borne epoxy water-reducible air/force dried coatings involves hazardous waste. The more corrosion-resistant formulations contain chromates, and therefore require disposal as hazardous waste. Some air pollution control agencies place severe restrictions on the emissions of chromate-containing particulates (overspray) that spray booth stacks emit into the air. A facility operator can overcome this problem by installing high efficiency dry filters, but must carefully monitor them to ensure that they do not violate the regulated limits. Chromates also contaminate the water in water-wash spray booths.

Other limitations relate to mixing. The coating comprises two or three components and therefore requires mixing prior to application. This automatically eliminates using such coatings as dip or flow coating primers. Also, depending on the formulation, mixing can be difficult if the unmixed viscosities are very high. Some companies use high powered mixers to mix components A and B. Other companies restrict their mixing to very small quantities. After adding water, the viscosity drops to manageable levels. End-users who wish to evaluate these coatings should work with their vendors before selecting a product. Evaluation should also take into account the fact that, like all plural-component coatings, the product has a limited pot-life.

Clean-up factors may complicate using these coatings. Depending on the formulation, operators sometimes find it difficult to clean equipment. In addition, removing coating from the skin (e.g., hands, face) of the operator can be difficult.

Finally, while the low application viscosities allow for low film builds, this can be a disadvantage when requiring higher film builds. For instance, when a specification calls for a minimum film thickness of 1.5 mil, the operator may need to apply two coats of the water-borne epoxy primer in order to attain this value. The need for the second application is both time-consuming and costly.

10.3.4 Polyurethane Dispersions

Polyurethane dispersions are water-borne systems that can air/force dry at temperatures below 194°F. Essentially, they are polyurethane lacquers dispersed in water; therefore, as the water evaporates, the coating film forms. No other curing mechanisms take place. In fact, these coatings are completely reacted products with no free isocyanate groups, so after the water evaporates the film is as hard as it ever will be.

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

10.3.4.1 Advantages

These products are quite versatile. They can coat metals, textiles, leather, wood, glass, paper, and rigid plastics.

The viscosity profile of those coatings offer several advantages. For instance, because of their relatively low application viscosities, operators can apply them with the most commonly used equipment. Also, operators can modify viscosity by adding water. Clean-up also requires water. These coatings require very little, if any, solvent, and only very small quantities of coalescing aids.

Another strength of these coatings are the films they produce. Coatings made from polyurethane dispersions dry to tough films of dependable hardness and flexibility. Films dry to predetermined gloss and color and, because these films do not chalk, both gloss and color retention are excellent. In addition, like all lacquers, no chemical change occurs during drying and exposure. Thus, the dry film retains its original properties for very long periods of time. Recoatability, such as for touch-up, is generally good and like lacquers even aged coatings can be recoated.

10.3.4.2 Limitations

The limitations of polyurethane dispersion products mostly revolve around actual application factors. These coatings have problems typical of water-borne finishes: drying time is dependent on temperature and relative humidity.

Regarding the film, like most lacquers, the total nonvolatile content is quite low (35 to 40 percent by weight). This means that multiple coats may be necessary for any good film build-up. Also, unlike solvent-borne lacquers, operators must ensure good intercoat adhesion because the topcoat does not tend to dissolve any previous coats.

Finally, surface cleanliness and freedom from any oil or grease both on the surface and in application equipment is essential for good film quality and adhesion.

10.3.5 Water-Borne Baking Finishes-Alkyd, Alkyd-Modified, Acrylic, Polyester

This group of coatings includes a wide range of products. So many different combinations exist that the end-user cannot assume that products available from one vendor are automatically similar to those formulated by another vendor.

While these water-borne baking finishes are available at low VOCs, the technology generally is still at the RACT level (for California). For instance, formulations are available that satisfy 3.0 lb/gal (360 g/L), less water, with some below the 2.3 lb/gal (275 g/L) levels. The VOCs including water are in the 1.5 to 2.0 lb/gal (180 to 240 g/L) range. Compared with their air/force dried counterparts, they have higher VOCs on both a “less water” and “including water” basis.

What these varied coatings share is that they cure at elevated temperatures, usually well above 250°F. Many vendors recommend curing temperatures in the range of 325^{o} to 350°F. Cross-linking occurs by formulating the basic resins with aminoplast resins such as melamine formaldehyde. Because of the high temperature curing requirement, these coatings are generally not appropriate for heat-sensitive substrates, such as plastics.

Typical of other thermoset coatings, these products exhibit properties such as hardness, mar and abrasion resistance, and excellent color and gloss retention, even when exposed to sunlight, chemicals, detergents, and solvents.

Typical end-uses include large appliances, supermarket shelving, steel racks used for merchandise storage in stores and warehouses, metal office furniture, metal laboratory and medical equipment, bicycle frames, lighting fixtures, automotive and transportation applications for components that can withstand relatively high baking temperatures, computer main frames and metal hardware for the computer and business machines industry.

10.3.5.1 Advantages

Most of these water-borne baking finishes are available at VOC levels that meet California’s limits of 2.3 lb/gal, less water. This is lower than the RACT limits of most other state regulations, usually 3.0 lb/gal, less water. Even with this favorable VOC profile, the performance properties of these coatings are often comparable with thermoset coatings, such as two-component polyurethanes and epoxies.

The coatings also have several advantages relating to their actual application. Because they have lower volume solids contents (30 to 40 percent), operators can usually apply them at lower film builds than their solvent-based, high solids (greater than 60 percent) counterparts. This can be advantageous when film builds must be controlled at approximately 1.0 mil. In addition, operators can use standard equipment to spray-apply these products. And it is possible to touch-up with self.

These coatings are also quite versatile. They can be applied on a wide range of metal substrates, such as steel, galvanizing, and aluminum, all of which can tolerate the elevated baking temperatures. In addition, they are currently available in a wide range of colors, gloss levels, and textures. Moreover, these products can serve as primers and topcoats, and in some cases one-coat systems are possible, particularly if surface preparation includes a well deposited iron or zinc phosphate.

Other favorable properties resemble those of other water-borne coatings. For instance, they pose a reduced fire hazard and have lower toxicity than solvent-borne coatings. Finally, like all water-borne coatings, operators require only small amounts of solvent for flushing out fluid spray hoses. They perform the primary clean-up with tap water.

10.3.5.2 Limitations

Many of the limitations associated with these water-borne baking finishes are due to the high curing temperatures they require. These coatings must usually cure at temperatures in the range of 325^{o} to 350°F. Curing time is inversely proportional to temperature. Facilities require high energy ovens, infrared lamps, or a combination in order to cure the coatings. Because of the high temperatures, the coatings are usually not appropriate for plastics, wood, or other heat-sensitive substrates.

For similar reasons, facilities can rarely apply this group of coatings to large assembled machines that may already be fitted with rubber hoses, hydraulic lines, leather, plastic upholstery, etc. Alternately, they can apply them to the metal components before assembly takes place.

Unless these baked coatings go through the full cure cycle (i.e., for a specified time at a particular temperature), they do not attain their optimum properties. Some formulations air dry to a dry-to-touch finish, making it difficult for the operator to easily determine (by sight) whether or not the coating has been properly baked. To prevent uncured product from being shipped, therefore, facilities must include quality control tests in their daily production schedule.

Another common problem of these products is outgassing and pinholing, which occurs when coating porous substrates such as sand castings. This phenomenon is due to the expansion of air in the porous cavities of the metal. To overcome the problem, facilities can first heat the metal to expel the air, but this adds another step to the coating process.

These coatings have other application-related complications, as well. Touch-up, for example, may require a second bake or use of another coating. In addition, many companies must prepare their metal surfaces with a minimum of 3-stage iron phosphate, although 5-stage iron or zinc phosphate is preferred.

Finally, like other water-borne resin technologies, operators may require a learning curve before being able to successfully apply these coatings. Also, like other water-borne coatings, problems such as edge pull and catering can occur, particularly if the viscosity of the coating is too low or the surface is not sufficiently clean.

10.4 Solvent-Borne Coatings

10.4.1 Overview

Although air pollution agencies actively promote water-borne coatings, all solvent-borne coatings cannot yet be replaced. Some companies will require solvent-borne coatings into the 21st century. Fortunately, VOC contents are gradually decreasing, viscosities are becoming more manageable, and paint chemists continue work on developing new solvents that are not VOCs, hazardous air pollutants (HAPs), or ozone depleting compounds (ODCs). These new solvents may offer a wide range of new opportunities.

10.4.2 Solvent-Borne Alkyds and Modified Alkyds That Air or Force Dry

This group of resin technologies has historically been the backbone of the coatings industry. Prior to the implementation of the VOC regulations, these technologies probably accounted for well over 50 percent of all industrial coating usage.

Alkyd resins are essentially oil-modified polyesters. They are a combination or reaction between an alcohol and an organic acid. Typically, the alcohols and the acids they incorporate are phthalic anhydride, pentaerythritol, maleic anhydride, glycerine, ethylene glycol, trimethylol ethane, and trimetfiylol propane.

Vendors can join acids and alcohols in various combinations, and under very precise and controlled conditions, to form a wide range of alkyd resins. Each resin or combination has its own distinctive chemical and physical properties. In addition, properties of alkyds such as hardness, gloss retention, color retention, sunlight resistance, etc., can be improved by modifying alkyds with other resins. Typical modifications add styrene, vinyl toluene, acrylics, silicone, or other polymers. Any of these modified products are more commonly known as modified alkyds.

Another way to modify the properties of alkyds is to have them react with oils. Depending on the ratio between the phthalic content and the oil content in the resin, the final product is known as a long-oil, medium-oil, or short-oil alkyd. Long-oil alkyds are commonly used for brushing enamels while medium- and short-oil alkyds are used for spraying and fast-drying applications.

Two more inevitable determinants of course are the vendor and the customer. The coating formulator chooses the appropriate resin or combination according to customer requirements. It is also clear that with so many possible variables in the formulation, the properties of these coatings must differ from one vendor to the next.

With the advent of the VOC regulations, coating formulators found this group of resin systems more difficult to reformulate into low-VOC alternatives than were other competing resin technologies. Coatings that meet the RACT limits of 3.5 lb/gal (420 g/L) for air/force dried coatings, however, are readily available, as are some that meet the California RACT limits of 2.8 lb/gal (340 g/L). They are associated with application problems though that end-users must consider before selecting such a coating.

10.4.2.1 Advantages

First and foremost, high solids compliant coatings are available at the RACT limit of 3.5 lb/gal (420 g/L), and at this level they perform well. Alkyds and modified alkyds are also among the least expensive of the VOC-compliant coating systems. Compliant coatings that meet California's RACT limit of 2.8 lb/gal (340 g/L) are also available but are more difficult to apply.

The application of these coatings are associated with several advantages. They air-dry at ambient temperature, although some vendors recommend that their formulations be force-dried at approximately 150°F for better results. Because they are single-component coatings, they do not demand much of a learning curve, nor do they need to be mixed like plural-component coatings. In addition, painters spray-apply these products using conventional air atomizing spray, airless, air-assisted airless, HVLP, and the full range of electrostatic spray guns. Finally, touch-up is easy to complete with the coating itself.

Facilities commonly use alkyds and modified alkyds as general-purpose shop primers for steel and other substrates, but not for zinc. Alkyd resins can be applied to most substrates including metals, wood, masonry, etc. For some of these substrates painters may need to apply a non-alkyd-based primer because alkyd resins tend to saponify. This is particularly true for galvanized and zinc-plated and zinc substrates.

In addition, because alkyd resins can be modified in so many ways, they are still among the most popular systems to use for general-purpose top coats. They are available in a wide range of colors and all gloss levels, and can produce a wide range of texture finishes. Finally, they appear to be the preferred coating to use for many low-to-medium cost items (particularly in cost-sensitive markets) or large machinery that cannot tolerate high temperature ovens.

Regarding the performance properties of these systems, they are similar to those of conventional solids alkyds. When high performance properties are required, however, such as resistance to strong chemicals or solvents, or color and gloss retention in long-term sun exposure, other resin systems are usually more appropriate.

10.4.2.2 Limitations

As stated earlier, alkyd coatings that comply with VOC regulations do exist. Historically, however, many companies have used alkyds containing an exempt solvent, particularly 1,1,1 trichloroethane (TCA), as a means of complying with stringent VOC rules. In recent years, 1,1,1 TCA has been listed by EPA as both an ODC and as a HAP. Moreover, 1,1,1 TCA will soon be phased out. Therefore, companies should no longer consider this avenue for complying with RACT regulations.

Although alkyds and modified alkyds have some advantages associated with their application, they also have several limitations. One of the primary limitations of the high solids formulations is their long ambient air-drying times (approximately 6 to 8 hours). This can be shortened by force drying. Some modified alkyds, however, do have faster drying times but also have other limitations. For instance, some fast drying modified alkyds cannot be recoated within a window of time. To illustrate, the repair coating may not be compatible with the first coat if the painter applies it within 2 to 10 hours after applying the first coat. Compatibility is good if recoating occurs before 2 hours or after 10 hours. The “critical recoating time” varies for each formulation and depends on film thickness.

In many cases it is very difficult to achieve a dry film thickness of 1.0 mil. Minimum dry film thicknesses tend to be in the range of 1.5 mil. This is particularly evident on complex geometries, such as weldments, assemblies, etc.; therefore, by default more coating is applied than the target piece actually requires. Another problem associated with film thickness involves the inability to uniformly atomize many of the high solids formulations. This results in variations in film thickness which leads to inconsistent gloss and color.

The viscosity of these coatings also often presents difficulties. They tend to exhibit higher viscosities than high solids polyurethanes of similar VOC content. In addition, some formulations require heating the coatings during spray application in order to adequately lower the viscosity for application.

Performance limitations are also important to consider. These coatings tend to be relatively soft initially. Hardness improves over a period of days to a final pencil hardness value of approximately HB. (Compare this with a pencil hardness of 3H to 6H for epoxies and polyurethanes.) See Figure 10-2 for an illustration of this hardness scale.

In addition, some alkyd polymers tend to have limited resistance to long-term ultraviolet exposure. Chalking and color fading are prevalent. This can improve if copolymerizing the alkyd with resins such as acrylics or silicones. The end-user must therefore be aware that for good exterior durability and resistance to sunlight, a modified alkyd will probably be necessary.

Finally, because of their poor alkaline resistance, facilities should not apply these coatings over substrates such as zinc and galvanizing, which tend to have an alkaline surface, particularly if corrosion has formed alkaline corrosion products between the zinc and the organic coating.

10.4.3 Alkyd Derivative Combinations That Cure by Baking

This group of coatings includes high solids alkyds, acrylics, polyesters oil-free, melamine- and urea-formaldehyde, and phenolics. Unlike the air/force dry alkyds, this group of coatings provides excellent physical and chemical properties. The primary difference is that cross-linking of the resins takes place when the coating attains a certain minimum temperature. For most such coatings, curing takes place at temperatures above 25O^{o}F, but the curing time may be too long (over 30 minutes) for most production painting facilities. The curing schedule is dependent on a time/temperature relationship, with curing times being inversely proportional to the temperature. Because the curing time may be too long (over 30 minutes) at the lower curing temperatures for most facilities, those using these coatings tend to cure the coatings for approximately 10 minutes at 350°F.

High solids baking alkyds are cross-linked with stabilized aminoplast resins such as melamine- and urea-formaldehyde. These initiate cross-linking when the coating attains high temperatures (greater than 250°F).

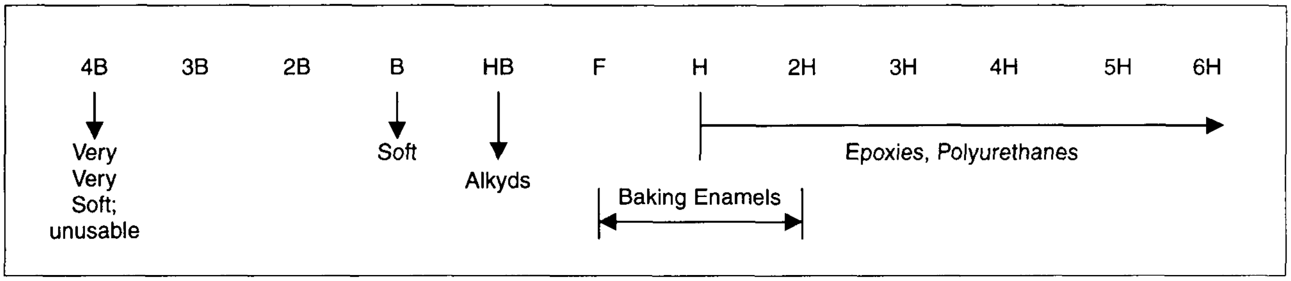


Figure 10-2. **Hardness scale for solvent-borne coatings.**

These coatings have properties similar to water-borne alkyd-type baked coatings. As with the water-bornes, these solvent-borne counterparts are commonly applied to steel shelving, steel racks used in stores and warehouses, metal off ice furniture and equipment, and large appliances (e.g., dishwashers, refrigerators, etc.).

10.4.3.1 Advantages

This wide range of formulations is available at VOC levels to meet most regulations, but usually do not drop below California RACT limits (which is 2.3 lb/gal). They are available at 3.0 lb/gal (360 g/L), and in some cases as low as 2.3 lb/gal (275 g/L).

As with most other compliant coatings, they are available in a wide range of colors and gloss levels. In addition, they can be applied directly to metal substrates, although they are not usually applied to heat-sensitive materials.

These coatings also exhibit excellent performance properties, such as good chemical and solvent resistance, hardness, mar resistance, good gloss, and good ultraviolet resistance (depending on the resin). They cure to excellent pencil hardness (2H), comparable with many epoxies and polyurethanes.

Operators also experience benefits when applying these baking alkyd derivative combinations. Many cases require no special application equipment. Moreover, because of their good adaptability to high-speed lines, these coatings are often applied with reciprocating electrostatic equipment, such as turbo bells and discs, on fast-moving conveyor lines. Another application benefit involves film thickness. With proper controls, an operator can achieve uniform thin film thickness of approximately 1 mil.

10.4.3.2 Limitations

Most limitations associated with the alkyd derivative combinations involve application process factors. For instance, like all baking systems, these require high-temperature ovens. They require baking at elevated temperatures with schedules such as 45 minutes at 230°F or 10 minutes at 350°F. These high baking temperatures preclude the coatings from being applied to plastics, wood, upholstery, or other heat-sensitive substrates.

Another requirement associated with these coatings is quality control procedures. These are necessary to verify that an acceptable coating has been applied. Quality control is especially important because working with them demands an operator learning curve.

The learning curve derives from several factors. High viscosities of some compliant formulations require special spray application equipment. HVLP spray guns need evaluation before implementing such a coating because atomization with some guns may be somewhat difficult to achieve. Atomization improves by applying the coating at fluid temperatures of 100° to 110°F. Installing an in-line heater can help accomplish this.

Special care also is necessary during surface preparation because stains caused by the spray washer cleaning process often "photograph" through the coating finish. As with many high solids coatings, operators may find it difficult to achieve smooth finishes free of orange peel. Another difficulty for operators is that some formulations remain tacky at ambient temperature in addition to leaving the walls and floors of spray booths tacky.

10.4.4 Catalyzed Epoxy Coatings

Catalyzed epoxy coatings constitute the counterparts to the water-borne epoxy coatings, but can achieve heaver film builds for many applications. For some applications, such as in the industrial maintenance industry, the higher film build is advantageous because water-bornes would require at least two coats to achieve the desired thicknesses.

Most commonly, these coatings are air- or force-drying, two-component materials comprising two separate packages: component A is the epoxy resin: component B can be a polyamine (e.g., diethylene triamine, triethylene tetramine, or tetraethylene pentamine), polyamide, polysulfide, or some other resin. For colored finishes, component A usually contains the pigments and other additives.

In the case of baking epoxy coatings, which cure during a high temperature bake of usually above 140° to 400°F the coating manufacturer preblends the two resins and supplies them as a single-component package. Examples include blends of epoxy resin with amino, urea formaldehyde, or melamine formaldehyde resins. Only when the applied coating attains an elevated temperature do the two resin systems react to form the cured finish.

Catalyzed epoxies are beneficial when requiring resistance to many chemicals, solvents, and alkalies, such as soaps and detergents. In addition, these coatings have excellent resistance to fresh water, salt water, and hot water. For these reasons they are a popular choice for protecting structures such as off-shore drilling platforms, ships, and bridges, where resistance to marine environments is critical. Facilities also use them to coat industrial and potable water tanks and pipelines.

Several coating vendors supply VOC-compliant primers and topcoats for the general metals and plastics industries. Depending on the application, VOC contents range from 1.4 to 3.5 lb/gal (168 to 420 g/L), but because they can be difficult to atomize, controlling film thickness can be problematic. Of course, the high film thickness that the low-VOC epoxies provide can be advantageous for some maintenance applications (e.g., bridges, chemical plants). By far, the majority of these coatings fall at the higher end of the range (closer to 3.5 lb/gal). Compliant epoxies are available that meet military specifications such as MIL-P-23377 (primer), MIL-P-53022 (primer), MIL-C-22750 (topcoat), and MIL-P-24441 (primer and topcoat systems).

When a decorative, corrosion- or chemical-resistant coating system is necessary, such as for bridges, chemical refineries, or off-shore drilling equipment, companies usually use epoxy coatings as the primer and undercoat, and then apply a more UV-resistant topcoat such as an acrylic or polyurethane.

10.4.4.1 Advantages

A great advantage of catalyzed epoxy coatings is that their VOC contents meet the RACT limits. In many cases, however, they are not as low as some of their water-borne counterparts. So, pollution prevention considerations suggest using water-bornes when possible.

The other advantages of these coatings relate to their performance. In general, epoxy coatings are known for their toughness, flexibility, and excellent adhesion to a wide range of substrates. These include most metals, plastics, wood, ceramics, masonry, glass, and more. Understandably, therefore, epoxies are a popular choice as primers. Importantly, they are the preferred choice as a primer under polyurethanes.

In addition, companies can obtain improved toughness and flexibility by reacting epoxy resins with polyamide resins. Unlike the polyamines (which are more commonly used in the industrial maintenance industry), they do not cause severe dermatitis in the operators, and their pot-life tends to be longer.

10.4.4.2 Limitations

One of the most notable weaknesses of epoxy coatings is their relatively poor resistance to ultraviolet light. For instance, when exposed to sunlight many epoxy coatings tend to chalk quite readily, which causes them to lose gloss and color. Although chalking takes place primarily at the surface of the film, it does not significantly affect the chemical properties of the coating. In fact, the coatings are often so resistant that operators may find it difficult to strip coating from damaged, coated parts.

Another important concern is safety. Painting operators must wear proper protective clothing and appropriate respirators during the mixing and application of the coating. If they do not and if the unreacted amine comes into contact with their skin or is inhaled, the operators can experience severe dermatitis and other health effects. Operators must therefore follow stringent safety procedures.

Other procedures that facilities must follow involve hazardous waste. As with all plural-component coatings, facilities must dispose of any unused, mixed coating as hazardous waste. Although facilities can minimize the amount of this waste by using a plural-component metering and mixing device, this option is usually only cost-effective when using large daily quantities.

Most limitations of these coatings, however, relate to application process factors. For instance, epoxy-polyamine coatings have a relatively short pot-life and must be used within a short time after mixing the two components. As the solids content increases, the pot-life usually shortens. For many formulations, a pot-life of 4 to 6 hours or less at ambient temperature is common. Manufacturers' technical data sheets provide further details. Some formulations also require an induction period of 20 to 30 minutes after mixing the two components, before the coating can be applied. Fortunately, the newer formulations are more forgiving and do not require such an induction time, but the operator must first confirm this, of course, with the coating vendor.

An important limitation is that operators should not apply epoxies at low ambient temperatures (less than 50^{o} to 60°F) because they will not cure properly. Another challenge for operators is film thickness. As with most high solids coatings, it can be difficult to achieve dry films of less than 1.5 mil, particularly when coating complex shapes.

Other concerns involve cleaning requirements both before and after using epoxies. Epoxies are more forgiving than most other resin technologies to surface preparation. They still, however, must be applied to a clean, well-prepared surface. And, as with all plural-component coatings, application equipment requires cleaning before the coating starts to set.

10.4.5 Catalyzed Two-Component Polyurethanes

Polyurethanes are a type of coating formed by the reaction of a polyisocyanate with a polymer that contains hydroxyl functionality. Vendors supply two-component polyurethanes in two separate containers, of which the first is component A and the second is component B.

Component A can either be clear or pigmented and offers a wide range of colors and gloss levels. The primary resin (polyol) is usually an acrylic, polyester, or polyether.

The second container, component B, is the curing agent and contains a multifunctional, pre-polymerized isocyanate. When end-users mix components A and B according to the manufacturers' prescribed ratios, the polymers react to form a highly cross-linked polyurethane.

When end-users require a two-component polyurethane with excellent chemical resistance, they often choose a polyester polyol for component A. When exterior durability and sunlight resistance are of greater importance than chemical resistance, they more commonly opt for an acrylic polyol for component A.

Facilities select polyurethanes for applications requiring a superior finish. The aerospace industry commonly uses them on items such as missiles, aircraft skins, and other aerospace components. In the transportation industry, they appear on buses, over-the-road trucks, rail cars that carry chemicals and solvents, automotive refinishing, as well as on some newly manufactured automobiles. The Army, Navy, and Air Force use-the coatings extensively on military ground support equipment such as tanks, personnel carriers, vehicles, etc., in which resistance to live chemical agents (CARC) is imperative. Polyurethanes are also used in the industrial maintenance, architectural, and wood furniture industries. In addition, they are popular for high-end consumer products such as machine tools, garden lawn mowers, snow blowers, tractors, etc.

10.4.5.1 Advantages

One of the most compelling features of these coatings is their VOC profiles. Most vendors of two-component polyurethanes can supply formulations at or below the RACT limit for California, which is 2.8 lb/gal (340 g/L). Higher VOCs may be necessary for some automotive refinishing colors and clears. Even these, however, are in compliance with RACT limits for other states.

In addition to a positive VOC emissions profile, two-component polyurethanes have attractive performance characteristics. These coatings are known for their excellent physical film performance: abrasion resistance, toughness, and hardness up to pencil hardness of 6H. Moreover, of all the resin technologies available, they rank among the best for resistance to most solvents and chemicals. Finally, they exhibit excellent outdoor durability (primarily the aliphatic polyurethanes), and are therefore popular for most of the transportation industry. Adding to their popularity is the fact that they offer a complete range of gloss and texture levels.

The process of applying these coatings also includes several advantages. First, they can be directly applied to steel, aluminum, plastics, composites, wood, masonry, and other material. In most cases, however, operators apply them over an epoxy primer. Polyurethanes also can cure at ambient (room) and elevated temperatures. They can even be used in under sub-zero conditions, unlike epoxies.

Because of the relatively low viscosities that the low-VOC polyurethanes exhibit, operators can spray-apply them with standard equipment. This includes conventional air atomizing, airless, air-assisted airless, HVLP, and electrostatic equipment. Unlike most other solvent-borne high solids coatings, the automotive refinishing industry, which demands good-looking finishes for customer acceptance, is currently using high solids polyurethanes. Moreover, these coatings are available in a wide range of solid and metallic colors with quick turnaround. This includes the availability of on-site intermixing of colors, predominantly for automotive refinishing. Another benefit for operators is that self touch-up is possible with these coatings.

10.4.5.2 Limitations

Many of the limitations of two-component polyurethanes reflect those of other plural-component coatings. For instance, two-component systems require mixing in prescribed proportions. Plus, as with all two-component systems, they have a limited pot-life. For some high solids polyurethanes, this can be less than 4 hours. In addition, like many high solids coatings, it can be difficult to achieve a uniform film thickness on complex shaped parts. This problem, however, is not as severe with polyurethanes as with other high solids resin technologies.

Cleaning requirements also resemble those of some other systems. Equipment requires cleaning before the coating begins to set. Finally, like most other coatings, operators must apply two-component polyurethanes over clean, pretreated surfaces.

Two-component polyurethanes also have more unique limitations. These coatings are expensive relative to competing technologies, but their enhanced properties usually offset this cost. In addition, paint operators must use appropriate respirators because polyisocyanates sensitize a small percentage of the population that comes into contact with them. End-users must consult their coating vendors for more detailed information.

10.4.6 *Moisture Curing Polyurethanes*

Moisture curing polyurethanes have an interesting mechanism. When a polyhydroxy resin pre-reacts with a polyisocyanate, but not completely, some unreacted isocyanate groups remain. The coating then cures in the presence of moisture from the air. Such materials are called moisture curing polyurethanes. Vendors supply this type of coating in one package, the second component being atmospheric moisture.

Although many would prefer single-component polyurethanes to two-component products, few companies currently sell moisture curing polyurethanes. This is because their manufacture is considerably more complex than two-component products. The complicating issue is that manufacturers must eliminate moisture from all ingredients they use.

Currently, the major supply of these coatings goes to military bases and military contractors who use camouflage moisture curing polyurethanes as the exterior coating for army tanks, personnel carriers, cranes, jeeps, and similar material.

10.4.6.1 Advantages

Moisture curing polyurethanes are desirable for several reasons. They possess no pot-life limitations because they are single-component products. They do, however, retain all of the performance advantages of two-component polyurethane coatings. Moreover, they achieve chemical-resistant properties more quickly than some two-component polyurethanes.

Although availability is scarcer than other types of coatings, the army has written specification MIL-C-53039 around the camouflage moisture cure polyurethane, and VOC-compliant coatings are available. Commercial coatings are also available in a limited range of colors, but end-users may need to shop extensively to find a coating satisfying their needs.

10.4.6.2 Limitations

Unlike two-component polyurethanes, currently only a few companies supply MIL-spec approved camouflage coatings, and this is also true for commercial colors. Like the two-component coatings, however, the operators must wear appropriate clothing and take similar health and safety precautions.

Regarding the application process, moisture curing polyurethanes are very sensitive to moisture contamination and therefore require special effort to keep moist air from the packaged or stored coating. In addition, the fluid hose leading to the spray gun and the headspace above the coating in the pressure pot or reservoir must remain free of moisture. Many companies use a nitrogen blanket or a desiccant to keep the headspace dry. Drying time also is affected by moisture in air. In very dry climates, the drying time may be longer than usual.

10.5 Specialized Coatings

10.5.1 *Overview*

This section discusses several specialized coatings. These are:

- Autodeposition
- Electrodeposition
- Radiation Cured Coatings
- Supercritical CO_2
- Vapor Injection Cure (VIC)

Each of these technologies has a narrow window of applications. For some end-users, one of these technologies will be the ideal choice. They are, however, unlikely to make a significant penetration into the total coatings market.

Regarding the VOC emissions profile of these systems, with the exception of UV Curables and some autodeposited coatings, none of the others technologies is likely to soon have VOC contents that approach zero.

Autodeposition and electrodeposition, however, do have favorable pollution minimization profiles. They have major advantages concerning VOC emissions as well as the disposal of hazardous waste and water pollution. Both technologies have low VOC emissions and when properly operated, generate essentially no liquid wastes. Also, because of the sophistication of these processes, water pollution is minimal.

UV Curables, Supercritical $C0_2$, and Vapor Injection are all spray application processes. If an operator can achieve low transfer efficiencies, hazardous waste will be much the same as for any other liquid coating process this chapter describes. If any of these five technologies are applied in a water-wash spray booth, water pollution generation will also be the same as for the other liquid coating technologies.

10.5.2 *Autodeposition*

Predominantly large coating users, whose annual throughput of metal is at least 1,000,000 square feet, would find this process cost-effective. Moreover, such companies are usually aware of this technology because they are sufficiently large to have on staff materials or coating engineers with access to the major coating technologies. Autodeposition is generally not a viable option for small or medium-sized coating users. Parker+Amchem Corporation of Madison Heights, Michigan, is the sole source for this technology.

During the autodeposition process, a resin in the form of a latex is electrochemically deposited on steel surfaces. Unlike electrodeposition, however, the deposition does not require an electric current.

The process is currently limited to steel, but the steel does not require pretreatment with a phosphate coating like iron or zinc phosphate. While the process can eliminate phosphating, it still requires superior cleaning that may comprise several stages.

The process includes at least the following:

- Alkaline spray clean (1 minute)
- Alkaline immersion (2 minutes)
- Plant water rinse (spray or dip)
- Deionized water rinse (spray; 5 to 10 seconds)

Operators then immerse the steel part in the coating tank at 68°F for approximately 60 to 90 seconds, after which it stands in air for a brief period to allow the coating reaction to continue. Thereafter, at least two more rinse stages follow. The first rinse involves immersion in tap water and the second is a non-chromate seal or a deionized water rinse.

Depending on the resin system used, the steel then enters either a two-zone or a single-zone oven. The curing temperature may either be 284^{o} to 356°F or 210^{o} to 230^{o}F, depending on the resin.

The coating consists of a pigmented water-dispersible (latex) resin, hydrofluoric acid, hydrogen peroxide, and deionized water. No solvents are used in the coating process. The coating has a very low-volume solids percentage of approximately 3 to 10 percent, and because of the hydrofluoric acid, the pH is in the range of 2.6 to **3.5.**

The coating can act as a primer and topcoat in one application, providing excellent salt spray resistance. Alternatively, it can serve as a primer that companies can overcoat with a wide range of coatings such as alkyds, epoxies, polyurethanes, etc.

Coating thickness is a function of bath solids, viscosity, density, and temperature. As the immersion time increases, the coating thickness increases. Because of this process, the coating can deposit on all surfaces that come into contact with the solution. It can deposit in holes, crevices, and otherwise inaccessible areas.

Although autodeposited coatings have limitations, they have a place in industry. They are currently used primarily for under-the-hood automotive applications, including:

- Leaf and helical springs
- Axle housings
- Lamp housings
- Engine mounts

10.5.2.1 Advantages

The primary advantage of the autodeposited coating is that VOC emissions are extremely low and, depending on resin, may even be zero. Also, according to Parker+Amchem, the coating is non-toxic and a very dilute solution can be disposed of easily. In addition, these coatings generate very little hazardous waste and pose little or no fire hazard. The very high transfer efficiencies (greater than 98 percent) that the efficient deposition process allows also contributes to pollution prevention.

In addition to its favorable pollution prevention characteristics, the coating conveys performance advantages. It is associated with excellent corrosion resistance and can also have excellent flexibility and impact resistance. Its hardness is beneficial for many applications, measuring at a pencil hardness of between 2H and 5H.

In addition, operators can achieve a uniform coating film thickness (0.6 to 1.O mil), which contributes to its uniform appearance. This process coats all cut edges and high-energy areas, which makes it ideal for fasteners. In this regard, it is even more efficient than electrostatic liquid spray painting applications

Basically, autodeposition avoids runs, sags, or similar defects associated with other organic liquid coatings, with the exception of electrodeposited coatings. As a primer, the performance of autodeposited coatings is apparently comparable with that of powder coatings, electrodeposited coatings, and polyurethanes.

Applying the process is also associated with benefits. Operators can immerse assemblies comprising steel, plastics, and rubber in the various stages of the process without affecting the non-metallic, heat-sensitive components. Only the steel will be coated. In addition, although the process requires thorough degreasing of steel, it does not require phosphating. Nor is an external electric current necessary in order to deposit the coating. This is the primary difference between autodeposition and electrodeposition.

Autodeposition offers an excellent method for applying uniform coating inside tubular steel and otherwise inaccessible areas. In fact, if immersing a nut-and-bolt assembly in an autodeposition tank, the process will properly coat the internal threading surfaces between the nut and the bolt. This phenomenon is not possible with electrodeposition. Another useful feature of autodeposition is that operators can topcoat it with most organic liquid coating systems.

It also does not always require high temperatures for curing. A low-temperature cure at 200° to 250°F achieves fully cured properties immediately. With some resins curing temperature may be higher, between 284° to 356°F. Infrared drying, however, is possible. Convection ovens are not necessarily required.

10.5.2.2 Limitations

A major limitation of autodeposition is that it is only suitable for steel substrates (cold or hot rolled). It is not appropriate for aluminum, zinc, plastics, rubber, etc. Even if coating steel, however, autodeposition is intended only for large production shops with high steel throughput. The process would not contribute efficiently to low volume coating facilities or those that coat a multitude of component configurations.

Surface cleanliness with this process is critical. Excellent degreasing may be necessary. The system may include up to seven separate cleaning or rinsing stages, most of which use immersion. Largely because of all these stages, autodeposition requires significant space allocation when compared with unsophisticated liquid spray coating lines.

Other labor intensive drawbacks also exist. For instance, hanging parts is important to achieve reliably uniform appearance on all parts. In addition, autodeposition requires frequent bath monitoring.

Finally, choices are minimal when ordering materials. Currently, Parker+Amchem Corporation constitutes the only provider of these coatings. Also, most colors available are black and greys.

10.5.3 Electrodeposition

As with autodeposition, predominantly large coating users whose annual throughput of metal is at least 2,000,000 square feet, would find electrodeposition cost effective. Again, such companies are usually well aware of this technology. Similar to autodeposition, this process deposits the coating electrochemically onto the metal surface. Electrodeposition requires, however, an implied DC current to carry out the process.

Metal parts pass through a multistage cleaning and treating process. Unlike autodeposition, however, thorough cleaning precedes a multistage zinc or iron phosphate process, which might include a chromate or chromic acid seal rinse and at least one deionized water rinse.

The next step then immerses the metal parts in the process coating tank containing the coating (5 to 20 percent solids dispersed in water). The workpieces are connected to a DC power supply and, depending on whether the process is anodic or cathodic, they will be charged either positively (anode) or negatively (cathode). This creates a strong electric field in the tank.

The electric field causes the coating with an opposite electrical charge to deposit on the metal surfaces. As coating deposits uniformly, it covers, and thus, begins to isolate the parts from the electric field. This process diminishes the strength of the electric field, which, in turn, slows down the coating process. When coating has totally covered the workpiece, no charged part is left exposed. This reduces the electric field around the workpiece to zero, and no more coating can deposit.

From the coating tank the workpieces pass through at least one deionized water rinse tank that washes off excess unreacted coating. They then travel to a baking oven that cures the coating at 275° to 375°F for 15 to 30 minutes. The excess rinse water/coating that the rinse tank recovers passes through an ultrafiltration unit that concentrates coating while recycling the water for reuse.

From an environmental perspective, electrodeposited coatings have approximately the same VOC content as conventional baking water-borne coatings. Hazardous waste disposal and the discharge of contaminated water, however, are considerably less. Because of the environmental benefits of electrodeposited coatings, EPA favors this technology over most other water-borne liquid coating technologies.

Typical applications include:

- Truck beds
- Engine blocks
- Water coolers
- Microwave ovens
- Dryer drums
- Compressors
- Furnace parts
- Housings for the automotive industry
- Shelving
- Washers
- Air conditioners
- File cabinets
- Switch boxes
- Refrigerators
- Transmission housings
- Light fixtures

- Farm machinery
- Fasteners

10.5.3.1 Advantages

Electrodeposition has excellent pollution prevention advantages. Because of its recycling ability, the process can achieve very high transfer efficiencies, greater than 98 percent. It also uses a low concentration of coating dissolved in water (5 to 20 percent solid dispersion in water); therefore, minimal solvent emissions generate from the tank. In fact, electrodeposition is associated with low hazardous waste and, in most cases, no discharge of contaminated water. In addition, because the coatings are water-borne, the process poses a low fire hazard.

Electrodeposition also has many performance strengths. Electrodeposited coatings can be applied to steel, galvanized steel, and aluminum. With all these, excellent uniform finishes are possible without runs, sags, etc. Also, because the process requires an electric field to promote deposition, it can achieve excellent uniform film thicknesses (approximately 1.0 mil). All sharp edges and cut ends become coated because the electric charge focuses at these points.

In addition, electrodeposition imparts excellent hardness (F-24) and good flexibility. The coating film also provides excellent corrosion and chemical resistance. Because of the high quality of coating and its inherent hardness and abrasion resistance, reject rates are low.

Another attractive feature is the extremely high gloss these coatings can provide. Because of this, automotive finishes are quite possible. Some coatings even act as both primer and topcoat in a one-coat finish.

Electrodeposition also has several advantages associated with the application process. Primarily, the automated nature of this process entails low labor requirements. Another attractive feature is that with primers applied by electrodeposition, operators can top-coat without sanding.

Finally, with electrodeposited coatings, choices are not limited. They are available in epoxy/urethane hybrids and other hybrids. The coatings also are available in a wide range of colors, although operators would apply large runs of only one color at a time.

10.5.3.2 Limitations

Although electrodeposition has some benefits regarding its application, most of its limitations are also application-related. Compared with other spray applied coatings, electrodeposition is a sophisticated coating process. It is generally not a viable process for small and medium-sized companies that either do not have sufficient throughput of material to justify the process, or manufacture workpieces of too many sizes and shapes. Facilities must invest very high capital expenditure for cleaning and pretreatment systems, coating tanks, oven, etc. For large facilities, the cost-effectiveness of the operation can offset these expenses.

The entire process has many requirements. First, it requires large floor space. It also requires proper system design to ensure that all hidden and inaccessible areas are coated. The coating process itself is very sensitive to cleanliness of the substrate. Then, the coating requires baking for 15 to 30 minutes at 275^{o} to 375°F.

Finally, facilities cannot use electrodeposition to coat plastics or other electrically non-conductive substrates. It also is not appropriate for multicolor finishing requirements; generally, the process works best when a company uses only one or two colors in its product line. This is because a company must usually dedicate a separate tank to a single color. Floor space and cost limitations may prohibit a company, therefore, from having many tanks.

10.5.4 Radiation Cured Coatings

These unique coatings cure when they are exposed to specific wavelengths of ultraviolet (UV) or electron beam (EB) radiation. Like the other specialized coatings, radiation cured coatings constitute the ideal choice for a very narrow niche of the overall coatings market. This manual includes them because their VOC emissions are very low, even approaching zero for some formulations. The coatings have low VOC emissions because curing takes place without the need for solvents to evaporate.

Because UV irradiation is low energy, the polymers of UV curable coatings contain special photo-initiators to promote cross-linking. The chemistry of the photo-initiators can be controlled through the concentration and type of formulation. EB coatings, on the other hand, require a high energy source so that the polymers can cross-link without the need for photo-initiators.

The primary resins used in UV and EB curable coatings are multifunctional acrylates, acrylated oligomers, and monofunctional diluent monomers. As individual, unreacted resins, diluent monomers are considered VOCs if they are allowed to evaporate. As the curing process takes place, however, they participate in the cross-linking reactions and form part of the solid coating film. Thus, while they qualify as VOCs in the unreacted state, they are not VOCs during the curing process. EPA has recognized that most of these reactive diluents are not emitted into the air during the coating process.

While EB coatings receive energy from an electric heated filament or cathode, low pressure mercury arc lamps generate the energy to cure the UV curable coatings. In order to ensure a consistent film cure, the mercury arc lamps must sit within a few inches of the coated substrate. This is why the substrate must have a very simple geometry, such as a flat or uniformly round shape. For instance, UV curable coatings are applied primarily to flat metal stock, and serve as the clear coating on coated screen or printed metal signs. Clear coatings are used as overprint varnishes on beverage cans, aerosol cans, lipstick containers, and similar items. Adding colored pigments to the formulation retards curing and extends curing times; therefore, most of the coatings being used are clear.

The rest of this discussion on radiation cured coatings focuses exclusively on UV curables because of their predominance in the paints and coatings industry. EB coatings are usually used in applications such as the manufacture of printing inks.

With few exceptions, facilities do not use radiation cured coatings extensively on general metal parts unless they have a very simple geometry. The wood furniture industry is beginning to try these coatings but application is still limited. As researchers continue to develop curing ovens (including the lamps) that are more forgiving to three-dimensional applications, these coatings will undoubtedly find numerous other applications.

10.5.4.1 Advantages

Radiation cured coatings have several pollution prevention benefits. Coatings are available with zero or very low VOC contents. Vapors from the process (e.g., from photo-initiator, surfactant, burn-off, etc.) are easily exhausted with no measurable air quality damage. Exhaust of irradiated cooling air also assists heat management and ozone disposal.

The unique curing process, of course, conveys many advantages. First, extremely short curing times, often less than 5 seconds are possible. This feature makes radiation cured coatings ideal for fast moving production lines (i.e., conveyor speeds of several hundred feet per minute). In fact, almost unlimited production speeds are possible when using efficient UV radiation at watt levels of 1,000 to 1,200 watts per square inch.

As stated, UV curing usually relies on medium-pressure mercury vapor lamps. Lamps emitting energy levels of several hundred watts/inch are available. At least one is also available that emits an energy level of 1,000 watts/inch. Another available energy source even cures photo-initiated chemistries instantly.

The distance from the substrate to the UV source becomes less of a consideration when sufficient UV energy is available. High UV energy can be applied to most substrates without heat damage.

Curing efficiency often relies on focusing the energy towards the substrate by means of reflectors. Reflectors can be elliptical, parabolic, or planar. They must have good thermal stability.

The performance of these coatings is versatile. By adjusting the formulation, an operator can modify viscosity, hardness, abrasion resistance, adhesion, flexibility, gloss, solvent resistance, and color. A key performance feature is their excellent adhesion to many substrates.

Facilities commonly use these coatings on flat-stock or uniformly round products. Examples include paper web, large decals, wood panelling, fiberboard, aluminum siding for interior or exterior exposure, coated coil products, cosmetic bottles, lipstick dispensers, compact discs, etc. The coatings can be applied to many plastics although checking the application is necessary to verify that the plastic has not embrittled.

Radiation cured coatings are readily available in clear finishes, and are now being explored for wood furniture. European furniture manufacturers have been using them for several years. Conversion is underway in the United States.

10.5.4.2 Limitations

Safety is a major concern with radiation cured coatings. Vapors from the coating application. process can be hazardous, and the system design must minimize operator exposure. Operators should wear respirators with organic vapor cartridges that have been approved by the National Institute for Occupational Safety and Health (NIOSH). Operator protection considerations must account for:

- Eyes
- Lungs
- Skin (which one can wash with citrus based cleaner)

These coatings also are quite limited in their applicability. They are not yet applicable to all shapes, and will not be until an energy source can irradiate all surfaces equally with the correct intensity of energy. The technology is not suitable for substrates with inaccessible areas, blind holes, crevices, and other areas not in direct exposure to the energy source. In addition, operators are limited as to coating thicknesses. Thicknesses of 0.1 to 0.5 mil are common. Thicker films may be more difficult to cure within a short duration.

Also problematic is the specific equipment and process requirements these systems must have. They require special ovens and energy sources. The distance of the energy source to the coated part must be within specified tolerances. The lamps are sophisticated. The reflector must be protected from heat and other process vapors. At the same time, the set-up of the lamps must optimize the energy distribution in the coating. Operators must be careful not to unnecessarily heat up, and especially not to overheat, the substrate. If any deterioration occurs, however, it is likely due to monomers in the chemistry formulation, not overexposure to UV.

10.5.5 Vapor Injection Cure

Vapor Injection Cure (VIC®) is a patented process that mixes a conventional two-component polyurethane prior to use. While an operator is applying the coating, a tertiary amine catalyst, dimethylethanol amine, is introduced into the atomizing or air shaping chamber of the spray gun. The catalyst acts as an accelerator for the polyurethane reaction.

This specialized process is not a pollution prevention technology in that it does not affect overall air, water, or waste emissions. End-users may be motivated to implement this system primarily because it accelerates the curing process of an already available low-VOC polyurethane coating, allowing operators access to the workpieces sooner. It, therefore, has cost benefits. Possibly, the coating setting faster may reduce handling damage, which in turn lowers the reject rate. Repainting fewer parts would reduce air, water, and waste pollution.

Apparently, this process can accommodate most types of guns, including conventional air spray, air-assisted airless, conventional electrostatic, and rotating atomizing discs. The coating can probably also be applied by an HVLP gun.

The tertiary amine is generated in a separate heated steel or aluminum vessel. Compressed air from the supply line feeds into the vessel where it picks up the tertiary amine vapor. The air/amine mixture then feeds to the air inlet of the spray gun. In order to prevent amine vapor from condensing in the air hose, the hose requires insulation or heat tracing.

10.5.5.1 Advantages

Many of the advantages of VIC are associated with speed. VIC allows rapid curing of two-component polyurethanes without shortening the pot-life of the premixed coating. Masking of sections for two-tone finishes can take place sooner. Sanding of primer can also take place sooner. Another feature speeding the process is that several guns can operate from one amine catalyst generator. In general, all these features combine to reduce shipping time of a coated product.

Despite the speed involved, VIC does not affect the physical and chemical-resistant properties of the polyurethane. In addition, the process prevents or reduces outgassing or air bubbles from porosities in casting.

10.5.5.2 Limitations

Most importantly, because amine vapor is a VOC, it does add to the VOC content of the two-component polyurethane. This can increase the VOC content of the applied coating by approximately 0.5 lb/gal. To ensure that the applied coating does not exceed the RACT limit, the coating vendor must formulate the two-component polyurethane so that the VOC content of the mixture of components A and B is at least 0.5 lb/gal less than the RACT limit. Health and safety concerns also may need addressing, but these should not differ from those of any other two-component polyurethane.

Other limitations involve either additional steps or costs. For instance, some electrostatic spray gun components may need modifying if they are sensitive to the amine catalyst. Generally, just a gasket change is necessary. Operators also must monitor and control the air/amine ratio. In most cases, operators must heat trace the air hose to the gun in order to prevent condensation of the amine catalyst. These and other VIC issues contribute to slightly increasing the cost of the coating system.

10.5.6 Supercritical CO_2 for Paints and Coatings

The Union Carbide Company has introduced their Unicarb® System which is designed to use liquified carbon dioxide (CO,) as a solvent for coatings.

Because of the excellent solubility characteristics of CO_2, the company claims that manufacturers can add less smog-forming solvents to conventional or high solids coatings. Liquified CO_2 can make up the balance.

While a system feeds the high solids coating to the spray gun, liquified CO_2 feeds to a chamber where it intimately mixes with the coating. The coating viscosity drops to a manageable level and excellent atomization takes place.

10.5.6.1 Advantages

The biggest advantage the Unicarb system offers is that it can reportedly reduce VOC emissions by as much as 50 to 80 percent (1). Many companies, but especially companies struggling to comply with increasingly stringent VOC regulations, should find this compliance option very attractive. In addition, because companies would substitute CO_2 for conventional solvents, they would also realize substantially lower solvent waste costs without compromising quality.

Companies can also greatly improve transfer efficiency. One company's application process saw a 30 percent increase in transfer efficiency (2). This improved efficiency contributed to a higher coating deposition rate and better ability to achieve the desired film thickness. Better transfer efficiency, of course, also translates into lower costs because less coating is used.

Other advantages include (1):

- CO_2 is much less toxic than organic solvents and has a much better health-effects profile.

- CO_2 has a significantly better safety profile because it is nonflammable and mostly inert.
- CO_2 is a low-cost product.
- The process uses recycled CO_2 and, therefore, does not contribute to the "greenhouse effect" (2).

The technology can also be used for applications other than conventional coatings, such as 100 percent solids lubricants. In this case, the $C0_2$, which is under high pressure, works to atomize the lubricant rather than lower the viscosity of the product (3).

10.5.6.2 Limitations

The capital expense associated with switching from a conventional system to Unicarb is relatively high. This is because expenses include a new array of special equipment to apply the system. Companies would also need to purchase coatings that have been specially formulated for this process (4).

Adding to initial expenses and difficulties is the learning curve. Whenever a company begins using a new technology, it can expect slower turnaround times and several glitches. Supercritical CO_2 technology is no exception. In fact, a wood furniture manufacturer in Pennsylvania found that the nonconventional "high-tech appearance of the system can be intimidating" (4). Companies must ensure their operators know how to control CO_2 temperature and pressure (two vital variables in the process) and how to start up and shut down the system.

In addition, companies should test various workpieces with this system to ensure quality finishes; it may not be appropriate for every workpiece. For example, the Pennsylvania manufacturer immediately realized high-quality finishes on chairs and vertical surfaces but experienced small bubbles (solvent trapping) on horizontal surfaces, such as tables (4). With patience and good testing procedures, however, companies may be able to resolve problems like this.

While a very attractive compliance option, supercritical CO_2 technology is not for everybody, partly because the coatings must be formulated specially for this system. One cannot take a conventional commercially available coating and simply spray with supercritical CO_2.

Currently, only one vendor, Nordson Corporation of Amherst, Ohio, makes the coating application equipment, while the license for the CO_2 technology is held by Union Carbide of Danbury, Connecticut. Possibly, therefore, companies located in the smaller towns and cities might find it more difficult to get on-site customer service.

10.6 Emerging Technologies

The term "emerging technology" does not necessarily mean, as many believe, a new and innovative technology providing some form of breakthrough. It also does not usually mean, as many in regulatory circles infer, a breakthrough to significantly reduce one or more forms of pollution.

In fact, many of the newer, specialized technologies such as radiation cured coatings, Supercritical $C0_2$, and Vapor Injection Cure, do provide some benefits but are not the panacea that the industry is waiting for. Moreover, they are unlikely to ever make a major dent in the overall coatings market.

The technologies making the greatest strides towards *zero* VOCs (and to a limited extent, also zero hazardous waste) are the water-borne and high solids coatings that this chapter has already extensively discussed. Changes occur gradually, and often comprise substitutions of only one ingredient at a time. For instance, a flow modifier of lower VOC content might be developed for polyurethanes, thus slightly lowering the overall VOC content of a formulation. Unless end-users keep up with current literature in the journals or attend special conferences, they are unlikely to know about these types of discrete developments.

Over a period of years, coating vendors gradually introduce modified formulations to their customers, and VOC reductions take place on an evolutionary basis. For instance, during the 1980s, formulating a two-component polyurethane with a VOC of 3.5 lb/gal was very difficult. By the early 1990s, many such coatings were readily available at VOCs of less than 2.8 lb/gal.

Perhaps the greatest advances are proceeding in the water-borne field. By 1994, manufacturers had developed water-borne single- and two-component polyurethanes with low VOC contents, less than 2.8 lb/gal, less water. Several research projects are underway to develop new cross-linking agents and emulsifiers for other resin systems in order to further reduce VOC levels.

The high solids arena has also seen major developments. By the end of 1993, a few coating manufacturers had already begun conducting preliminary production trials on 100 percent solids baking coatings. They are gathering more test data before offering these coatings to the industry at large.

Importantly, many of the new developments are taking place in generic technologies that the industry is currently using, such as water-bornes and high solids. For the most part, then, end-users will be able to implement the new formulations without making major modifications to their existing processes. This is a great advantage. For instance, switching from a liquid coating to a powder coating requires a complete change in manufacturing philosophy. A major portion of a coating facility would require modification before implementing powders. Alternatively, changing from a conventional 1994 water-borne coating to a zero VOC water-borne may require only minor process changes. As these technologies become more readily available, local vendors will introduce them to end-users.

10.7 Selecting the Best Technology for Specific Applications

After studying all the technologies that this chapter presents, the end-user should follow the steps noted below to narrow the best choice for his or her facility:

- Eliminate those technologies that obviously do not apply.
- Create a list of those technologies that look feasible.
- Review the lists of advantages and limitations again to determine whether any of the technologies on the list can be eliminated.
- Call coating vendors to solicit samples of the technologies that remain.
- Arrange to conduct laboratory-type tests that will further differentiate between the most likely and least likely options.
- Obtain larger samples of the technologies that passed the laboratory phase, and commence with limited production tests.

In some cases, the end-user will not have the proper equipment (e.g., a high temperature oven, dip tank, powder coating spray gun) to conduct these tests. Usually, coating and equipment vendors can make arrangements to conduct the production tests at a third-party location. Often, the coating or equipment vendors even have in-house applications laboratories where these tests can be conducted.

At this point, the end-user should have sufficient information, both technical and financial, to make the final selection. Arrangements can proceed in implementing the selected technology.

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Chapter 11
Powder Coatings

11 .1 Introduction

11.1.1 Pollution Prevention Considerations

Of all the coating technologies on the market, powder coatings are particularly popular for their low volatile organic compounds (VOCs) content. For many applications, powders offer cost advantages over either solvent- or water-borne liquid technologies. Moreover, powder coatings provide many pollution prevention benefits. The act of applying powder coatings does not contribute to air, water, or hazardous waste pollution.

A powder coating facility does, however, generate some pollution, primarily from two associated processes. The first and most important involves surface preparation. Like liquid coatings, operators apply powders over well-degreased surfaces, which receive an iron or zinc phosphate. Chapters 5 through 8 covered these processes in detail, including best management practices.

The second important pollution-generating process is the stripping of powder coating from hooks and reject parts. Chapter 14 will cover this subject. Then, Chapter 15 discusses spray booths, including pollution prevention strategies.

Several books and manuals on powder coating exist. In addition, those seeking to learn more about the subject may choose from numerous conferences and workshops each year. Anyone considering powder coatings should remember that they have inherent pollution prevention characteristics versus conventional technologies.

11.1.2 Decision-Making Criteria

Decision-making criteria relevant to powder coating, as addressed in this chapter, are highlighted in Table 11-1.

11.2 Suitability for Specific Applications

11.2.1 Suitable Applications

Powder coating can benefit many applications. In addition, the list of parts for which it is being used, as well as the list of industries that use powders, continue to grow. Powder coatings are ideal for metal parts that have relatively simple geometries and surfaces that are all reasonably accessible. Because of this, powders are currently being used for automotive under-the-hood applications. These products include oil filters, air filters, shock absorbers, coil springs, lamp housings, and more. The architectural products industry is using powders to coat interior and exterior aluminum extrusions, air conditioning equipment, aluminum windows and doors, window and door screening, etc. In the miscellaneous metals industries, the use of powder coating is quickly moving toward having equal status with liquid coatings.

In addition to all these successful applications, the automotive original equipment manufacturers (OEMs) are currently evaluating using powders as base coats and clear coats.

Almost every industry that finishes metal products has at least some companies that use powders. Powders, however, are not for everyone. The section below elaborates on this.

11.2.2 Unsuitable Applications

Many applications are unsuitable for powder coatings because they either:

- Are not appropriate for the particular surface.
- Cannot provide corrosion protection equivalent to high-performance liquid coatings.
- Are not cost competitive with liquids.

One factor in the powder coating process that largely contributes to its application limitations is the heat that powders require for curing. For instance, certain metal alloys may lose critical metallurgical properties when cured at elevated temperatures for a long period. Powder coatings also are unsuitable for large parts that cannot enter a high temperature oven. (Some low temperature epoxies that cure at approximately 250°F are available). Other materials inappropriate for the powder coating process include thermoplastic or heat-sensitive plastics, wood, upholstery, rubber tubing, etc.

Color may also be a complicating factor when using powders. For example, powder coatings are not well suited for short runs of multiple colors. In addition, cus-

Table 11-1 Decision-Making Criteria Regarding Powder Coating

Issue	Considerations
Is powder coating a suitable option for the workpiece?	• If workpiece is small enough to fit into a commercial oven that would operate at 325° to 400°F, consider powder coatings; if not, additional research would need to determine if powder coatings can be applied practically and cost effectively. • If workpiece comprises heat-sensitive material, such as wood, plastic, upholstery, hydraulic tubing, electronic equipment, accurately machined parts, it might not be practical or cost-effective to powder coat because of potential damage; if workpiece does not comprise such materials, consider powder coatings. • If workpiece is a fully assembled machine that contains any flammable material, such as gasoline, powder coatings can probably not be considered. • If workpiece can be well-cleaned and treated with an iron or zinc phosphate, consider powder coatings; if not, additional research might be required and the end-user should seek advice from vendors or consultants. • If geometry of workpiece is relatively simple (such as flat surfaces), consider powder coatings; if geometry is relatively complex (difficult-to-reach areas, many brackets, channels, etc.), additional research might be required and the end-user should seek advice from vendors or consultants. • If coated workpiece will be exposed to aggressive corrosive environments, such as a petroleum refinery, severely corrosive marine atmosphere, etc., additional research might be required and the end-user should seek advice from vendors or consultants; if not, consider powder coatings. • If workpiece requires extensive masking prior to coating application, additional research might be required because powders might not be practical or cost-effective; if workpiece does not require extensive masking, consider powder coatings. • If the workpiece requires coating with more than one color, as in two-tone products, additional research might be required and the end-user should seek advice from vendors or consultants; if the workpiece requires coating with just one color, consider powder coatings. • If coated workpiece will be post-formed, machined, or worked on, powder coatings might be an excellent choice because they are malleable and can tolerate handling often with minimum, if any, damage. • If coating operation uses many colors, predominantly in small quantities, additional research might be required because powder may not be cost-effective under these conditions.
Is workpiece small enough to be suspended from a conveyor?	• If yes, consider an enclosed spray booth that reclaims the powder. • If no, operators may need to apply the coating in a large walk-in booth, and powder reclamation might be impractical.
Does the coating operation comprise long runs of the same workpiece?	• If yes, facility might be able to automate the application by means of reciprocators or stationary powder guns, thereby minimizing the cost of labor. • If not, employing manual operators to apply the coating might be more cost-effective.
Does the workpiece comprise many faraday cages?	• If yes, operators might be able to effectively coat the relatively inaccessible areas or acute angles by. means of a tribo-charging powder gun. • If no, either a corona- or tribo-charging gun are possibilities.
Which powder coating material should a facility select?	• A facility should consult with a powder coating vendor before selecting a resin technology.

tom colors may not be easily available in quantities of less than 1,000 lb (although some vendors do specialize in small batches).

Finally, other types of applications that are usually unsuitable for powder coatings are:

- On parts that cannot tolerate warpage.
- On parts that require thin films (less than 1 mil).
- For porous castings in which air blisters would mar the final coated finish.

11.3 The Powder Coating Process

Generally, powder technology, as a group, is the fastest growing coating technology in the organic coatings market. In some industry sectors, it is rapidly competing with and penetrating the liquid coatings applications market. The primary reason for this success is its favorable environmental profile. Unlike liquid coatings, powders essentially do not contribute to air, water, or hazardous waste pollution.

As the name implies, powder coatings are organic coatings that are supplied in dry powder form. Unlike liquid coatings, each discrete powder particle contains the entire coating formulation, namely the resins, pigments, fillers, and modifiers. A powder coating contains no solvents. The powder particles are extremely finely divided and resemble talcum powder.

The powder coating process entails two basic steps:

- Applying the coating onto a pretreated part
- Curing the coated part in an oven

11.3.1 Applying the Coating

Operators can use one of three primary methods to apply the powder coating:

- Electrostatic attraction by corona charge
- Electrostatic attraction using tribo-charging guns
- Fluidized bed

In both of the electrostatic methods, the parts to be coated are suspended from an electrically grounded conveyor.

The first method listed is the most common. To charge the powder, the operator uses a gun that contains a high-voltage electrode. Upon pulling the gun trigger, the high electrical potential around the electrode ionizes the surrounding air, causing a corona. As powder particles leave the gun and pass through the charged air, the electrostatic charges transfer to the powder particles, which then become attracted to the grounded part. The individual particles essentially “adhere” loosely to the metal substrate; at this stage, the only mechanism particles use to adhere to the substrate, or to each other, is electrostatic attraction.

The second application method also uses a gun, but one that comprises internal passages made of plastic, usually nylon. As the powder particles rub over the plastic, they receive an electrostatic charge, much like the phenomenon that occurs when running a comb through one’s hair on a dry day. Once again, when the particles leave the gun, they seek the grounded part and loosely adhere to it by electrostatic attraction.

In the fluidized bed approach, the powder is contained in a tank. The bottom of the tank comprises a porous plate. Low pressure air passes through the plate causing the powder to become suspended in the air as a cloud. In fact, this cloud is known as a fluidized bed. The part to be coated must be preheated to a temperature usually in excess of 400^{o}F, and is immediately immersed into the fluidized bed. Upon contact, the powder particles melt and remain on the heated substrate. The higher the par-t temperature or the longer the part remains in the fluidized bed, the heavier the film build. This assumes that the temperature of the part does not drop to below the melting point of the powder.

Note that none of these methods involve solvents or generate hazardous waste. Also, clean-up efforts are minimal, benefitting both pollution prevention and time and material resources.

Regardless of which method operators use to apply the coating, the coated part must then enter an oven. In the oven, the powder melts, fuses, and cures into a hard, chemical- and abrasion-resistant coating.

11.3.2 Curing the Coated Part

Curing of the powder entails heating the powder-coated part in a convection oven at a temperature of between 325°F and 400°F (163^{o} to 204°C) for approximately 8 to 20 minutes. Developments are underway to lower the curing temperatures to 250°F (121°C). Two variables that affect the curing period are time and temperature. For instance, the lower the curing temperature, the longer the curing time, and vice versa. Another variable affecting the curing period is the mass of the part.

An alternate method for curing the powder uses an infrared oven, which heats only those surfaces that are exposed directly to the infrared rays (i.e., the coating). The advantage of infrared curing is that the entire workpiece does not have to reach the curing temperature in order for curing to take place. Because of this fact, infrared curing can provide cost savings.

When the powder coating is oven cured, some vapors-approximately 0.5 to 5 percent by weight of powder coating-are emitted into the atmosphere. These comprise mainly water and some organics. The organics are not solvents, but rather plasticizers or resins emitted at the high baking temperatures. To a large extent, the emitted vapors that have high boiling points condense on the oven walls as they pass through it. It is questionable whether they are truly VOCs as defined by EPA. In fact, most air pollution regulatory agencies assume that the emissions from powder coating operations are essentially zero; therefore, operators are usually not required to measure or record their emissions. In addition to advancing pollution prevention, this is a major economic benefit.

As soon as the part leaves the oven and cools to ambient temperature, it can be handled, worked on, and shipped.

The fully cured coating is extremely hard and abrasion-resistant, and exhibits excellent physical properties. Depending on the resin system, the coating can also be resistant to chemicals, solvents, sunlight, and most of the other chemical properties that are associated with high-performance liquid coatings.

11.4 Costs Associated With Powder Coating

For a facility operator considering either switching to or adding powder coating capabilities, cost analysis of equipment and other requirements should encompass the following areas:

- General and environmentally related costs
- Costs of materials
- Pretreatment costs
- Costs associated with actual coating process
- Costs associated with heating/curing

Most importantly, regarding pollution prevention opportunities in powder coating facilities, major cost savings are probable in the area of environmental compliance. For instance, one company recently calculated an annual cost of hazardous waste disposal for its liquid coatings to be in the order of $30,000. By converting to powders, that cost would essentially drop to zero. Similarly, the conversion would dramatically reduce costs associated with obtaining air permits, administering emissions inventories, etc.

Converting to a powder coating application, however, would require that the operators learn how to use these coatings. Any training costs, however, should be offset by the fact that applying powder coatings is less complicated than applying liquid coatings. For expertise, however, the facility operator may decide to hire a relatively experienced supervisor to oversee the operation.

Regarding materials, when coating the same number of workpieces, the costs for liquids and powders are somewhat comparable. Liquid coatings are purchased by the gallon, while powders are purchased by the pound. The rule of thumb in the industry is to equate 3 pounds of powder to 1 gallon of liquid coating. Powders range in cost from $2.50 to approximately $6.00 per pound, depending on the resin type, color, texture, etc. Exotic powders are more expensive. Alternately, costs for liquid coatings can vary from $10.00 per gallon for some of the low-end resin formulations to $90.00 per gallon for polyurethanes. Costs for some polyurethanes in exotic colors can even exceed $150 per gallon. While it may be difficult to make a cost comparison based on the per pound versus per gallon measures, the industry's rule of thumb is to assume that for the majority of scenarios, the cost solely of the coating materials are approximately the same.

The cost of equipment, of course, depends on the degree of sophistication of the facility. Most pretreatment requirements, however, are universal. The facility will need a pretreatment system at least comparable to that which a high-performance liquid coating system requires. If the facility already has a 3- or 5-stage iron or zinc phosphating system for steel parts or a conversion coating system for aluminum parts, no new pretreatment equipment is necessary. Alternately, a facility lacking such equipment would have to install it. The costs to install a pretreatment system vary according to size and throughput of material, but for most painting facilities the range is usually $50,000 to $120,000. Of course, a facility operator intending to install a pretreatment system in order to apply powders would also need to do so for liquid coating application. In the past, many liquid coating painting facilities could avoid the installation of a sophisticated pretreatment system because the high-VOC liquid coatings were somewhat tolerant to surface contamination, With the introduction of high solids and water-borne coatings, however, this is no longer true; therefore, with current technologies, liquid or powder, a sophisticated pretreatment system is necessary.

Unlike the pretreatment phase, the actual powder coating process is associated with many options. Pans can be coated on conveyors or racks and, provided that liquid and powder coatings are not applied on the same line, it may be possible to use existing conveyor or rack equipment.

Spray guns and associated application and electronic control equipment can cost from $5,000 to $100,000 per facility. Portable units are available for companies that use only small quantities of powder or that coat on an intermittent basis.

If a facility uses a few standard colors in reasonably large quantities, the operator can feasibly purchase one dedicated powder coating booth for each color. When the facility is using a specific color, that particular booth is rolled in-line with the conveyor system.

In addition, a device is necessary to filter the overspray powder from the exhaust air. Cartridge filters, or cyclone/bag houses may be appropriate for this purpose.

If a facility operator intends to use both liquid and powder coatings, then the operator may consider having two separate dedicated coating lines: one for liquid and one for powder. This, however, might require more facility floor space.

If, on the other hand, the facility operator intends to replace its liquid coatings with powder coatings, then a major retrofitting may be necessary. This would require a shut-down period for the powder coating equipment to be installed.

The final step of the powder coating process involves heating and curing the coated piece. This step requires ovens, but because solvents do not evaporate from the coatings, only low air replenishment is required. The oven, which can be a convection, infrared, or similar type, must be capable of raising the coating temperature to approximately 325°F to 400°F (163°C to 204°C). Some cases may require higher oven temperature, particularly when using special high-performance coatings such as nylon.

Generally, however, energy costs are considerably higher for powders because these coatings cure at elevated temperatures. These costs, though, must be balanced against savings realized from emitting no solvents.

11.4.1 Profiles of Economic Impact of Switching to Powders

Case histories of the economic and environmental benefits of powder versus liquid abound in the literature. Monthly or bi-monthly journals such as *Powder Coating Journal, Metal Finishing, Products Finishing, Industrial Paint and Powder* (formerly *Industrial Finishing),* regularly publish case histories demonstrating the advantages of the dry versus the wet technologies. Each year in the United States, at least two national conferences are devoted to powder coatings. Examples of typical cases are presented below.

First, in most cases, a clear economic advantage exists for converting from liquid to powder coatings (1). The Return on Investment (ROI) results in a short payback period. Liberto reports that American Yard Products, producers of walk-behind and riding mowers, enjoyed substantial cost savings. The company's total powder conversion investment was $2,150,000. When comparing this cost with the company's annual operating cost reduction from powders, which was $2,354,870, it is clear that the benefits in this case were dramatic. They were also quick; the projected payoff period was only about 11 months (1).

The next profile is of the Self-Serve Fixture Company of Texas, which manufactures a line of shelving and fixtures for the self-serve retail market. It switched to powder in January 1991 and within the first year saved approximately $100,000 solely on material usage. In its previous liquid painting operation the company estimated a transfer efficiency of 40 percent, which implies that 60 percent was wasted. Changing to powder led to a significant improvement; it realized 85 percent efficiency for colors that could be reclaimed and recycled, and 55 to 60 percent for custom colors for which it was not economical to reclaim the powder. The improved quality of the finish contributed to a 20-percent increase in sales in 1992, and the president of the company projected another 15 percent for 1993 (2).

American Desk, a leading manufacturer of business and institutional furniture, had been using high solids, solvent-borne coatings. In 1993, the company partially converted to powder due to high environmental costs, waste disposal, and high solvent throughput. Their new powder coating system comprised a 5-stage washer, 6-minute dry-off oven, 2 powder coating booths, 28 powder guns, and a 25-minute bake oven. Bailey reports that because of the increased line speed and improved parts hanging technique, the powder coating system was able to increase productivity by 50 to 100 percent. Moreover, the powder coating line, which operates two shifts per day, produces more than the previous liquid painting system that required three shifts (3).

Maytag-Galesburg, manufacturer of refrigeration products, converted to powder in 1992 as a voluntary effort to comply with EPA's "33/50" initiative. This initiative called on large companies to voluntarily reduce their emissions of 17 listed toxic chemicals by 50 percent before the end of 1995. According to Schrantz, this change allowed the company to increase its production capacity. At least one benefit was that the cost of reject or repair parts due to frequent handling during manufacture and assembly was dramatically reduced because of the increased durability of the polyester powder coating (2).

11.5 Advantages and Limitations of Powder Coatings

11.5.1 Advantages

Facilities considering using powder coatings have a comfortable range from which to choose their coatings. Powder coatings are available in several resin formulations: acrylic, polyurethane, epoxy, polyester, epoxy/polyester hybrids, TGIC, nylon, etc. This technology also offers a reasonable range of colored, clear, and textured coatings. In addition, depending on the resin system, powders are available in various gloss levels.

These coatings are associated with other advantages, too. They have excellent physical performance properties, and many powders have excellent machinability as well. Powders also are associated with excellent salt spray resistance. Partly because of these attractive features, military agencies are starting to accept powder coating as replacement for liquids.

The largest advantages to a powder coating process derive from its application benefits and, especially, its pollution prevention benefits.

Regarding application, powder coatings allow operators to:

- Coat all sharp edges and cut ends.
- Provide thin to heavy film builds in one application (they usually require no primer).
- Apply coating to hot or cold parts.

Powder coatings also prove very economical for long runs of a few colors. They are especially adaptable to robotic or reciprocating application and, generally require less skill than application of liquid coatings.

Finally, another feature of applying powder coatings that should interest many facilities involves masking. In some cases, masking is not required because uncured powder can be brushed off critical surfaces before the coated part enters the curing oven.

The pollution prevention opportunities associated with powder coatings, however, probably offer the greatest advantages. These opportunities relate to high transfer efficiencies, the cleanliness of the powder coating process, and the lack of hazardous waste.

Operators can achieve very high transfer efficiencies with powder coatings. They can even attain transfer efficiencies of greater than 95 percent if powder overspray is collected and recycled.

In addition, powder coating is a relatively clean process, particularly if facilities operate spray booths under negative pressure. Regarding clean-up, to a large extent an operator can clean the spray booth using compressed air. Solvents may only be required during the final stage of cleaning.

Perhaps the most attractive advantages to powder coatings relate to their hazardous waste profile. Liquid coatings are applied in dry filter or water-wash spray booths, and either the filters or the wastewater require disposal as hazardous waste. Powder coatings, on the other hand, are always applied in dry filter booths. The filters, however, generally do not require discarding. Instead, cartridge filters in modern powder coating booths are designed so that operators can reclaim the powders that collect in the filters. The filters are good for hundreds if not thousands of pounds of powder. Facilities can eventually dispose of the filters either as solid hazardous waste (if the entrapped powder contains heavy metals) or can discard them in a landfill.

In addition, waste powder that might fall to the floor outside the booth, can be swept up into a small pile, placed into an oven where it melts into a solid block, and be discarded either as solid hazardous waste or in a landfill. The economic benefits from the environmental considerations are sufficient reason for many facilities to convert from liquids to powders.

This pollution prevention profile of powder coating translates specifically into:

- Emissions of almost zero VOC content (0.5 to 5 percent by weight).
- Minimal generation of hazardous waste (if any).

11.52 Limitations

As with all systems, powder coatings also have limitations. Some of these relate to heat requirements. Most decorative resin systems require temperatures of 325°F to 450°F (163°C to 204°C) for curing. Some functional resins require temperatures in excess of 500°F. Apparently, however, some epoxies are available that only require 250°F (121°C). Because of these needs, powder coatings are associated with high energy usage.

Regarding personnel, although an earlier section described the powder coating process as uncomplicated to perform, it does require a skilled operator to set up guns for each run, and check for quality before parts enter the oven. Also, powder coating often requires manual touch-up by an operator who stands at the end of an automated booth. Other quality-oriented tasks involve ensuring that the metal surfaces for coating have been well-cleaned and treated, as well as seeing that the oven remains clean so that dust and other contaminants will not blow onto the coated parts during coating.

When considering the coating process itself, electrostatic equipment makes it difficult to achieve high film thicknesses (greater than 5 mil), unless the part is preheated prior to the coating application. Of course, most cases do not require 5 mil. In addition, in fluidized bed applications, operators cannot easily control film thickness due to differing heat contents of the metal assembly (i.e., light gauge metal fixed to casting).

Another example of challenges associated with the powder coating process involves the difficulties associated with coating “faraday cages” unless using alternative techniques. A farady cage is the area inside an acute angle that is shielded from the electrostatic field. For instance, if the inside of a box is to be powder coated, it might be difficult to deposit powder onto the inside corners of the box. The inside surfaces of a channel bracket or the area between the fins of a radiator all represent faraday cages. Recent years have seen new methods to overcome some of these problems. In particular, the tribo-charging gun appears to successfully coat many of these surfaces. Moreover, powder coatings can be more difficult to repair after curing when compared to liquid coatings.

Finally, capital equipment outlay is generally greater for powder coating than for conventional coatings ($5,000 to $100,000). Small or portable systems are available, however, which are less expensive. Because each case is different, the costs for converting to powder can be comparable to those for liquid coatings. Costs seem to rise when a facility operator intends to use an automated system.

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Chapter 12

Viscosity Management for Pollution Prevention

12.1 Introduction

12.1.1 Pollution Prevention Considerations

This chapter discusses one of the most important properties of a coating, namely viscosity. Viscosity is a measure of the degree to which a fluid resists flow under an applied force.

Controlling viscosity has an indirect yet important effect on pollution prevention. Best management practices that control viscosity do not, in and of themselves, diminish air, water, and waste pollution. With proper viscosity management, however, operators can achieve more acceptable finishes, dramatically reducing the number of reworks and rejects. Repainting fewer workpieces reduces all forms of pollution.

Coating manufacturers often attempt to formulate products that can be used as packaged. Sometimes, however, the spray painter must make adjustments, such as diluting the coating, in order to obtain an acceptable finish. Unfortunately, most spray painters do not fully understand their options, and hence rejects and reworks abound, particularly with high solids coatings.

The purpose of this chapter is to provide a better understanding of the available techniques for beneficially altering the viscosity of a coating.

Decision-making criteria relevant to viscosity management are not specifically called out in a table because the recommendations discussed throughout this chapter should be followed by all facilities.

12.2 Description of Viscosity

A thorough understanding of the concept of viscosity as well as the parameters that affect it can be very useful in applying coatings efficiently and minimizing rejects and reworks.

Consider a basic example. Water has a low viscosity compared with cold syrup. Upon heating, however, the syrup's viscosity drops and it flows more easily. This, of course, is a simplistic example of viscosity. Because the subject is more complex a few definitions may be helpful.

Absolute dynamic viscosity is the force per unit area that resists the flow of two parallel fluid layers past one another when their differential velocity is 1 cm/set per centimeter separation (1). Figure 12-1 illustrates a liquid lying between two parallel plates (2). Suppose that the tower plate is fixed, while the upper plate can move to the right at a velocity (v) under the action of an externally applied force. With this movement, the liquid between the two plates would distort as shown. One of the parameters illustrated here is shear stress. By definition shear stress is as follows:

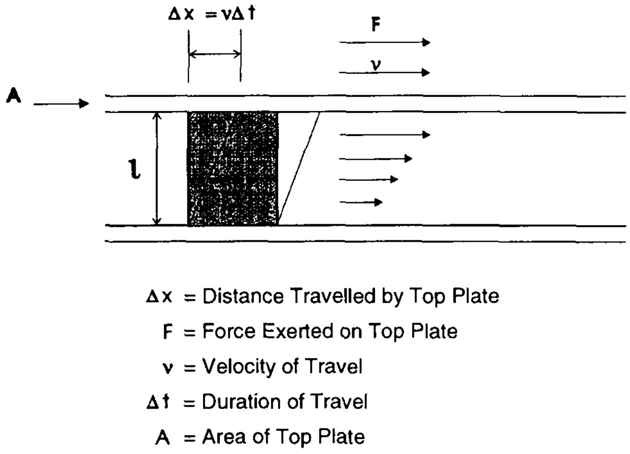

Figure 12-1. The concept of viscosity (2).

$$\text{Shear Stress} = \frac{F}{A} \qquad \text{(Eq. 12-1)}$$

where A is the area of the top plate and F represents the force exerted on the top plate.

Another important parameter is shear strain, which is:

$$\text{Shear Strain} = \frac{\Delta x}{l} \qquad \text{(Eq. 12-2)}$$

where l is the distance between the two plates, and Δx is the distance that the upper plate has moved.

Figure 12-1 also shows how the velocity of the fluid changes from zero at the lower plate to vat the upper.

Therefore, over a period (Δt) the fluid at the upper plate moves a distance $\Delta x = v\Delta x$.

The coefficient of viscosity (η) is defined as the ratio between the shear stress and the rate of change of the shear strain:

$$\eta = \frac{F\iota}{Av}$$

Viscosity is usually expressed in terms of poise or centipoise (cp), where:

$$1\ poise = 100\ cp$$

The units of absolute viscosity, poise or centipoise, are gm/(cm)(second).

Finally, a measure of kinematic viscosity is given in stokes, where:

$$\text{Stokes} = \frac{\text{poises}}{\text{density}}$$

Although most people will never have a need to perform the calculations presented in the preceding definitions, the calculations do illustrate a couple important points. First, they make clear the many variables that affect viscosity. Second, they lay the groundwork for understanding much more commonly used definitions regarding viscosity. These common definitions follow.

A Newtonian liquid is any liquid for which the shear stress is proportional to the shear rate. If the ratio of shear stress to shear rate is small and the effect on viscosity is not constant, the liquid is non-Newtonian (2).

For instance, when measuring the viscosity of water, which is a Newtonian liquid, the viscosity remains constant regardless of how fast it is stirred.

A near-Newtonian liquid is one for which the variation of viscosity with shear rate is small and the effect on viscosity of mechanical disturbances, such as stirring, is negligible.

A non-Newtonian liquid is any liquid that does not satisfy the requirements for a Newtonian liquid. Such liquids have plastic flow, pseudo-plastic flow, or dilatant flow. For each of these, the shear rate is not proportional to the shear stress.

For plastic flow, the liquid must overcome or exceed a yield stress before flow will take place. No yield value exists for pseudo-plastic flow and the curve of the plot of shear stress versus shear rate is non-linear, with the shear rate increasing faster than the shear stress. For fluids exhibiting dilatant flow, the viscosity increases as the shear rate increases. The curve of the plot of shear stress versus shear rate is non-linear, with the shear stress increasing faster than the shear rate.

Finally, the consistency of thixotropic materials depends on the duration of shear as well as on the rate of shear. To better understand this property, one can imagine how the viscosity of an acrylic latex paint changes as it is being stirred. For instance, when stirring the paint very slowly with a stick or paddle, its viscosity is relatively high. As stirring becomes faster and more vigorous, the viscosity drops. When stirring ceases altogether, the viscosity increases again, although it may not increase to its original value. Figure 12-2 demonstrates the relationship between viscosity and shear rate for a thixotropic fluid.

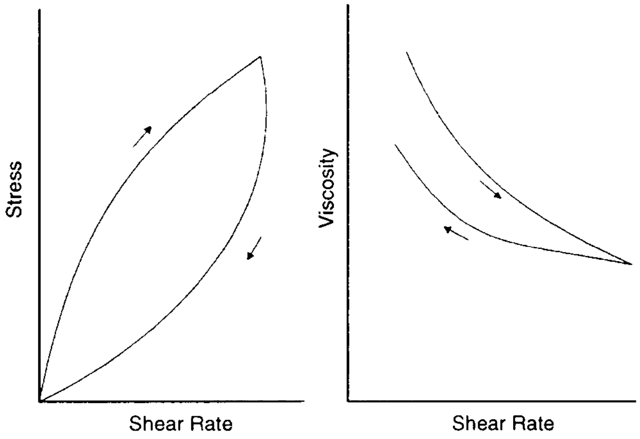

Figure 12-2. Thixotropy.

A coating with thixotropic properties may have a relatively high viscosity while being pumped from a pressure pot to the spray gun. As the coating is forced through the very small orifice of the gun, its viscosity drops appreciably and remains relatively low while the particles travel from the gun to the target. As they settle on the target, such as a vertical panel, the viscosity rapidly builds up again, thus minimizing the possibility for the coating to run or sag.

12.3 Measuring Viscosity

Viscosity is one of the most important coating properties in determining if the coating can be applied to an acceptable finish. This is why measuring viscosity is so important.

The most commonly used viscometers for measuring paint on a production line are gravity type cups such as the series of Zahn cups (#l, #2, #3, and #4) and the Ford cup (#2, #3, #4). All require little skill and can be used by paint operators who have been shown how to use them.

12.3.1 Zahn Cup

The Zahn Cup is made of stainless steel and resembles a cup as shown in Figure 12-3. It has a small orifice at

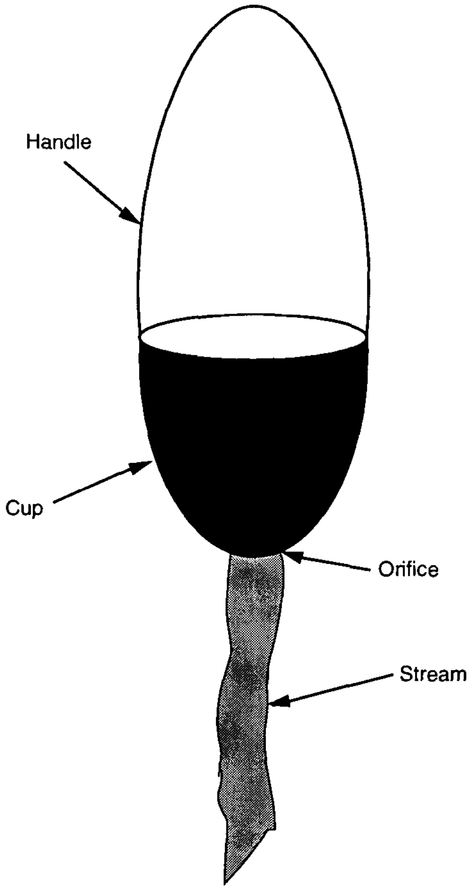

Figure 12-3. Zahn cups.

the bottom and a stainless steel handle braised to the top which allows an operator to hold the cup during the measurement. The operator first stirs or agitates the coating to ensure proper homogeneity, and then carefully immerses the cup itself into the body of the paint. The operator quickly withdraws the filled cup from the paint, but loosely holds it only a few inches from the top of the coating container, ensuring that it hangs down vertically. The coating flows from the orifice of the cup back into the container.

Immediately after withdrawing the cup from the paint, a stopwatch is started. As soon as the stream of paint breaks, the operator stops the watch and records the reading. Provided that the coating stream undergoes a clean and single break, the viscosity of the coating is measured by the seconds the coating requires to efflux to the break point.

This method for measuring viscosity is easy to implement, and is cost-effective because Zahn cups cost approximately $70 to $80 and require relatively little skill.

A disadvantage of the cup is that it is not suitable for highly thixotropic coatings. With more viscous coatings the stream may break once, then flow again for a few seconds and break again, and continue in this fashion until the last drop of paint effluxes from the cup. Many spray painters record the viscosity measurement after the very first break, but this is inaccurate for thixotropic coatings because the orifice of the cup is too small. For more viscous coatings, operators should use a cup with a larger orifice, such as the Zahn #3 or Zahn #4. Table 12-1 provides guidelines for selecting the correct cup. Remember that the most reliable viscosity is measured when the coating makes only one break.

Table 12-1. Zahn Cup Orifice Sizes (3)

CUP	Approximate Orifice Size (in.)	Recommended Centistokes Range	Range in Zahn (secs)
1	0.078	15 to 78	31 to 60
2	0.108	40 to 380	19 to 60
3	0.148	90 to 604	13 to 60
4	0.168	136 to 899	12 to 60
5	0.208	251 to 1,627	10 to 60

Another disadvantage of the Zahn cup is that when the operator withdraws it from the coating, excess material flows not only through the inside of the cup but along the walls on the outside. This influences the number of seconds before the stream breaks.

For facilities that do not require precise viscosity control, Zahn cups are probably the most practical and the least expensive.

12.3.2 Ford Cup

The design of this stainless steel viscometer is also based on gravity feed, but it differs from the Zahn cup in that it incorporates a lip to collect excess coating. Moreover, the cup is not immersed in the coating but is held in position in a specially designed stand which is placed on a laboratory table top (see Figure 12-4). The Ford cup that the coatings industry most often uses is the Ford #4 cup.

Before measurement begins, the temperature of the coating is determined and recorded.

To measure viscosity, the operator collects a sample of the coating from its container or pressure pot and carefully pours it into the Ford cup until the coating overflows into the lip. While doing this, the operator places a finger under the orifice of the cup to prevent coating from effluxing. Acontainer, such as a pint can, which is placed under the cup collects the coating.

Upon readiness, the operator starts the stopwatch and removes the finger from the orifice. Immediately, the coating starts to efflux into the pint can. Once again, the stopwatch is stopped when the first break in the coating stream occurs. Unlike the smaller Zahn cups, the orifice

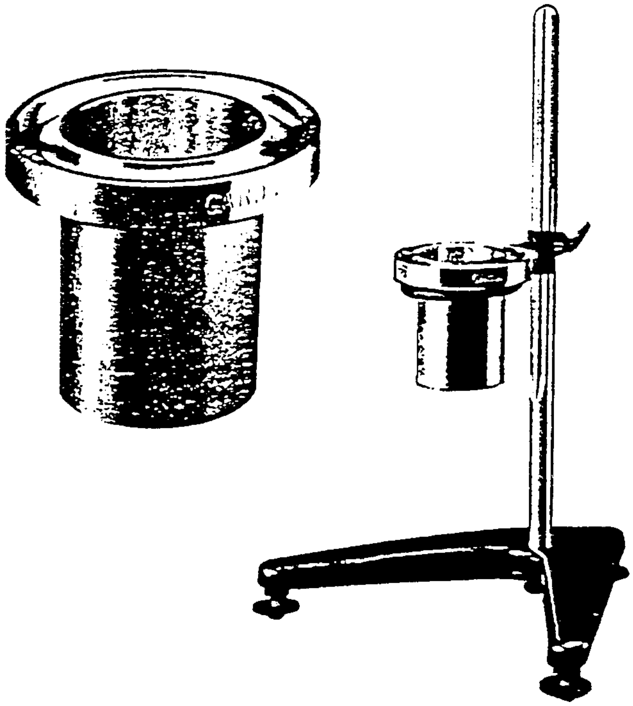

Figure 12-4. Ford viscosity cups (photo courtesy of Pacific Scientific Catalog publisher).

in the Ford cup is usually large enough so that one clean break takes place regardless of viscosity.

Although paint operators use the Ford cup less frequently than the Zahn cup, it is the standard method for measuring viscosity in a paint manufacturing laboratory. It has the advantage that no coating flows down the walls of the outside of the cup to interfere with the viscosity measurements. Facilities that use the paints and coatings usually prefer the Zahn cup because it is less expensive and simpler to use (i.e., the operator need not transfer coating from the container or pressure pot to the cup).

If the coating is to be applied at an elevated temperature, it is preferable to measure the viscosity at the same temperature. This, however, may be impractical in many facilities. An alternative to measuring the viscosity at the application temperature is to measure it at ambient temperature, and then determine what viscosity is required under ambient conditions to yield the desired application viscosity at application temperature.

12.3.3 Brookfield Viscometer

A major disadvantage of the gravity type viscometers is that they do not reflect the true viscosity of non-Newtonian and thixotropic coatings. Because many water-borne and some solvent-borne products fall into this category, the gravity type viscometers are inappropriate.

A Brookfield viscometer can determine the apparent viscosity and the shear thinning and thixotropic properties of non-Newtonian fluids in the shear rate range of 0.1 to 50 per second-’ (4).

Three methods exist for characterizing the rheological properties of the coating. The first consists of determining the apparent viscosity of a coating by measuring the torque on a spindle rotating at a constant speed. Unfortunately, this method only measures the viscosity at one rotational speed so one cannot fully understand the non-Newtonian nature of the coating.

The second and third methods consist of determining the shear thinning and thixotropic (time-dependent) rheological properties of the coating by measuring viscosity at a series of rotational speeds of the spindle. The agitation of the coating immediately before measuring the viscosity is closely controlled. Measurements show the correlation between the drop in viscosity with increasing rotational speed, and also the increase or recovery in viscosity when lowering the rotational speed. When the shear rate is high, the behavior of the coating under true application conditions provides more accurate information as to how the coating will behave after it has been applied.

When measuring only the apparent viscosity, the operator uses a constant rotational velocity, usually 200 rpm. Brookfield viscometers contain a spindle or paddle designed to rotate at this constant speed (see Figure 12-5). The instrument then measures the energy required to maintain this constant shear rate, and since the viscosity of thixotropic coatings is directly dependent

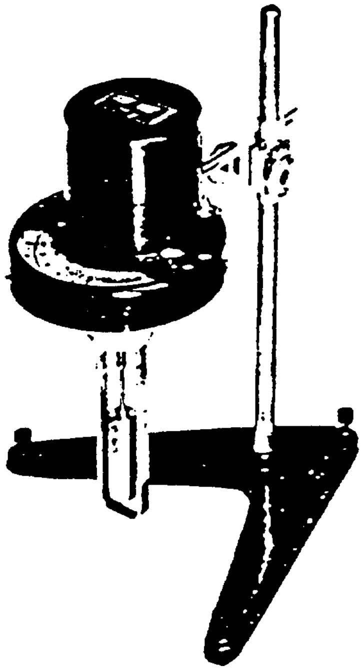

Figure 12-5. Brookfield viscometer (photo courtesy of Pacific Scientific Catalog publisher).

on the shear rate, the instrument is appropriate for this type of measurement.

As with all viscosity measurements, the operator should measure viscosity at the application temperature. If this is not possible, however, the viscosity can be measured at a standard ambient temperature and viscosity can then be extrapolated to the operating temperature.

Unlike the gravity type viscometers, the Brookfield instruments do require a certain degree of skill to achieve repeatable results. These instruments are well worth using, however, when the uniformity of film appearance is critical, such as in the automotive industry.

12.4 Guidelines for Best Management Practices (BMPs)

As stated earlier, properly managing viscosity prevents pollution by limiting the number of rejects and reworks. Fewer rejects and reworks means less materials, less waste, and less pollution, as well as less cost. BMPs for controlling viscosity include the following:

- Measuring viscosity.
- Maintaining constant temperature.
- Drawing a viscosity/temperature chart.
- Specifying an acceptable range of viscosities.
- Developing alternatives for achieving acceptable finishes.
- Using heat to reduce viscosity.
- Minimizing waste disposal by choosing appropriate mixing procedure.
- Recognizing thixotropic properties of water-borne solvents.

12.4.7 Measuring Viscosity and Temperature

Measurement of viscosity by the paint operator should not be optional because this coating property helps determine whether the operator can achieve an acceptable finish. In measuring viscosity, the operator should also measure the temperature of the coating.

To ensure constant viscosity throughout the working day, the spray booth and the coating in the fluid hose leading to the spray gun should remain at a constant temperature. This can be accomplished in one of two ways:

- A facility may opt to use an air make-up unit to control the inlet air to the spray booth, but must consider the cost of heating the air. Large spray booths, particularly downdraft ones, have high air throughputs (usually well in excess of 20,000 cfm) so the cost of energy is high. Many paint facilities, particularly those in cold climates, already have air make-up units installed.
- The facility can heat the coating to a constant temperature, usually above ambient. Even facilities with air make-up units on their spray booths can benefit because the coating must often travel to the booth from a mixing room that may be quite a distance from the booth. The coating that reaches the booth from the uncontrolled mixing room may be cold in the morning and warm in the afternoon.

An operator should draw a viscosity/temperature chart before qualifying or using any coating for the first time. Measuring the viscosity of the coating at progressively higher temperatures accomplishes this. The operator must ensure, however, that solvent does not evaporate from the coating while it heats.

The procedure for preparing a viscosity/temperature chart using a Zahn cup follows:

1. Mix the coating thoroughly before sampling.
2. Fill a quart can with the coating and measure the temperature, and then determine its viscosity with the appropriate Zahn cup. (Clean the cup before reusing.)
3. Take the lid from the can and punch a small hole through the center. Insert an impeller or paddle through the hole and replace the lid on the container. Then place the can in a larger container of warm water. Thoroughly stir the coating and measure the temperature. After the temperature rises by an appropriate amount, such as 5°F, measure the viscosity again. Continue in this fashion, always adding warmer water to the outer container, until several points can be plotted on a chart.
4. If the ambient temperature is too warm, add ice to the outer container to cool down the coating below ambient.

The viscosity/temperature chart is very useful because it allows the spray painter to interpolate or extrapolate the appropriate viscosity when mixing the coating at the beginning of the shift. For instance, if the paint is cold when starting in the morning, instead of adding solvent to lower the viscosity, the spray painter can set the in-line heater to the temperature that yields the most appropriate application viscosity.

12.4.2 Specifying a Viscosity Range

The coating facility should specify an acceptable narrow range of viscosities that are compatible with the spray equipment. Thereafter, quality control tests on incoming material should ensure that the coating vendor supplies the same viscosity from batch to batch. If end-users do not perform such tests, they can expect batch to batch viscosity differences. This may not make a noticeable difference for manual spray gun applications but it will affect the finishes produced by automated guns, whether on reciprocators or on robots. Viscosity control is critical when applying metallic coatings; otherwise, apparent color differences can lead to rejects or reworks.

12.4.3 Developing Acceptable Alternatives

If the coating is VOC compliant but the spray gun cannot achieve an acceptable finish, several alternatives are available. One alternative might be to experiment with different spray guns. For instance, if currently using an HVLP gun the end-user should experiment with HVLP guns from other vendors. If this does not solve the problem, trying different spray gun types, such as air-assisted airless or electrostatic, may help.

Also, if the coating is a single-component formulation, such as an air/force dry coating, or one that bakes at an elevated temperature, the end-user should experiment with a closed loop, recirculating, in-line paint heater. The advantage of heat is that it not only lowers the viscosity of the coating but also tends to produce a more uniform finish.

12.4.4 Using Heat To Reduce viscosity

Although this topic is closely associated with the practice just described, its importance cannot be overstated. The use of heat rather than solvents to reduce viscosity is one of the most effective strategies for minimizing solvent emissions into the air. Facilities should consider in-line paint heaters for both water-borne and solvent-borne, single-component coatings. The end-user must discuss with the paint manufacturer the efficacy of using heat to adjust viscosity of the coating. The manufacturer can determine whether heat will be beneficial. Paint heaters are discussed in more detail in Section 12.7.3.

12.4.5 Minimizing Waste Disposal

To minimize the disposal of waste from mixed plural-component coatings, a facility should carefully consider the manner in which the coating is mixed. Chapter 10 provides several guidelines but a summary follows.

12.4.5.1 Batch Mixing

For small batches, usually less than 1 gallon, it probably is best to premix the components in batches rather than to install a proportioner and mixing device. When using many colors in small quantities, usually less than 1 gallon, it also probably makes more sense to premix the components. When selecting the premix option, the spray painter should mix only as much coating as the job requires.

Pot life is the time that elapses after a plural-component coating has been mixed, until its viscosity is so high that the operator can no longer achieve an acceptable finish. If the coating has a short pot life, the spray painter should mix only as much coating as can be applied before reaching the pot life. If the pot life needs to be longer in order to avoid wasting valuable material, the operator can cool the coating but should not chill it to a temperature that will cause condensation of moisture from the air to settle on the surface of the mixed coating.

Pot life should not be extended by adding solvent to the mixed coating. Not only may this cause the coating to exceed the regulated VOC limit, but the solvent may remain entrapped in the applied coating and lead to paint failures several months or years after the coating has been applied.

12.4.5.2 In-Line Mixing

When a facility uses relatively large volumes of plural-component coatings, such as epoxies and polyurethanes, it might be beneficial to install proportioning equipment. Such equipment is designed to continuously measure the exact ratios of the components being fed to the spray gun. For instance, an epoxy might be mixed in the ratio of 4 parts component A, 1 part component B, and l/2 part thinner.

A small stainless steel or plastic static mixer is inserted into the fluid hose only a foot or so upstream from the spray gun. A static mixer is nothing more than a short tube, approximately 8 inches long and with a diameter of about 3/4 of an inch. On the inside of the tube are a series of baffles that force the coating to repeatedly change direction as it passes through the tube. As the unmixed components enter the static mixer, the baffles cause extensive turbulence of the components, so that when they emerge from the mixing tube, they have been thoroughly mixed.

This strategy is probably the most effective for minimizing air, waste, and water pollution, and for cutting the costs associated with the disposal of the waste material. The cost to install a proportioner and mixing device will be offset by the savings. A facility can expect a cost-payback within a few months, depending on the quantities of coatings used.

Proportioners are ideal when using relatively large quantities, usually larger than 1 gallon, of a single color on a regular basis. They can be justified even when using many colors, but the quantity of each color must be large enough to warrant the use of the equipment.

12.4.6 Recognizing Thixotropic Properties

When using water-borne coatings, the spray painter should try to apply them at the highest viscosity that will give an acceptable finish. The spray painter should have little need to reduce the coating with water. Because many water-borne coatings are thixotropic, they can be spray applied at higher viscosities than most solvent-borne coatings; therefore, the spray painter should not assume that the application viscosity for water-borne coatings should be the same as for solvent-borne coatings.

12.5 Managing Viscosity Differences for Different Coatings

When reducing (thinning) coatings, it is important to recognize the different viscosity trends for solvent-borne and water-borne coatings. Figure 12-6 shows the viscosity trend when reducing two different resin technologies with the same solvent. The reduction in viscosity is somewhat predictable; that is, if adding solvent to each coating in small but equal increments, the viscosity reduction will follow a uniform curve. Because of this predictability many spray paint operators thin their coatings instinctively, without either measuring exactly how much solvent they add or determining the final coating viscosity by means of a suitable viscometer.

Conventional low solids, solvent-borne coatings have traditionally been spray applied at viscosities of 18 to 25 seconds and measured on a Zahn #2 viscosity cup. Alternately, the newer higher solids formulations need to be sprayed at viscosities as high as 35 seconds, or even higher, which require measurement on a Zahn #3 cup.

With water-borne coatings, additional complexities arise. Some formulations behave similarly to solvent-borne coatings in that viscosity reduction follows a uniform curve, as shown in Figure 12-7, Water-Borne Paint #2. Although the curve may have a similar shape as that for the solvent-borne paint, the entire curve is shifted to higher viscosities.

A misconception exists among spray painters and others that all coatings must be applied at approximately the same viscosity. Thus, when changing from a high solids, solvent-borne coating to a water-borne, many painters immediately want to reduce the paint with water to bring down its viscosity to so-called manageable levels. This, however, is not always appropriate. For example, Figure 12-7 shows the preferred application viscosity for a solvent-borne paint as determined by the spray painter. It is possible that Water-Borne Paint #2 would need so much diluting water to bring down the viscosity to that of the solvent-borne application viscosity, that the thinned paint would be transparent and run down vertical surfaces.

Viscosity management becomes more complicated when the viscosity/reduction curve is not uniform, as is the case for Water-Borne Paint #1 in Figure 12-7. Initially, the viscosity of the coating is relatively high and remains high even with the addition of small increments of water. As more water is added, the viscosity drops precipitously before leveling out at even higher dilution concentrations. If a spray painter were to apply Water-Borne Paint #1 at the "preferred application viscosity," the over-diluted coating would be transparent and would simply flow down vertical surfaces. The spray painter might not be aware that it may be possible to apply

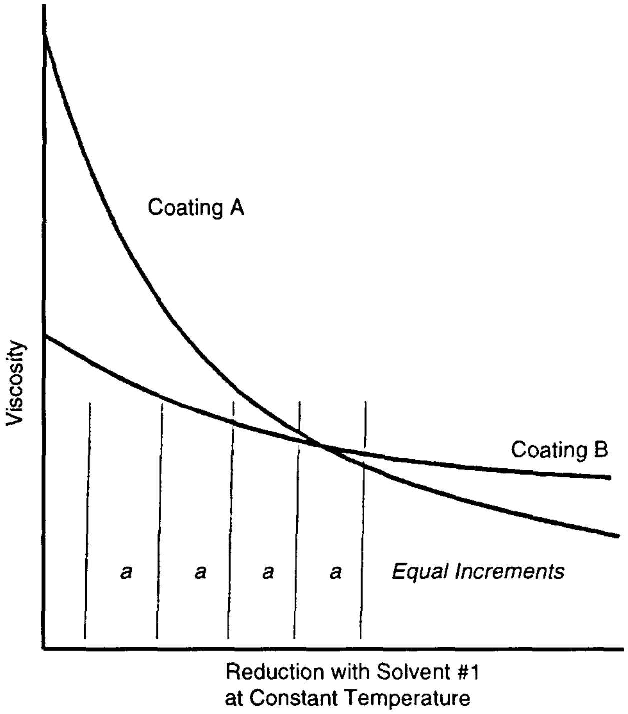

Figure 12-6. Effect of solvent reduction on viscosity.

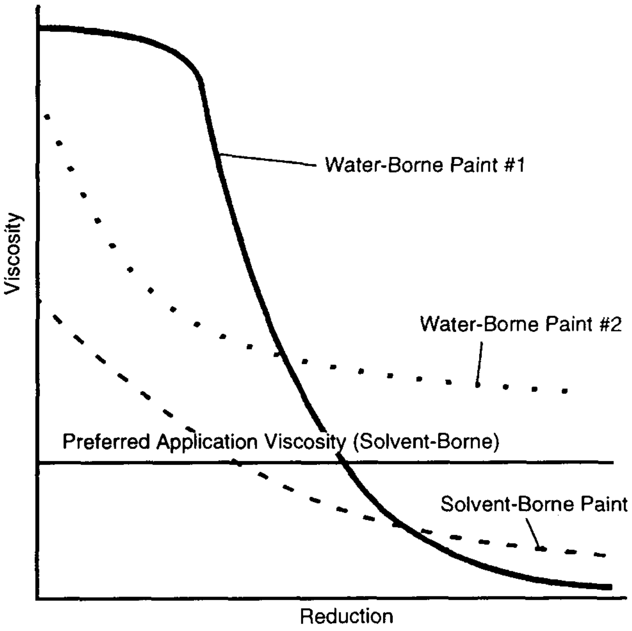

Figure 12-7. Effect of reduction on viscosity for water-borne coatings.

Water-Borne Paint #1 at its high package viscosity without any need to thin with water. Thus, with current coating technologies, the concept of a preferred application viscosity for all coatings does not exist.

Unfortunately, vendor literature is not always sufficiently clear on how much dilution a coating can tolerate. Most spray painters who are new to the application of water-borne coatings tend to want to over-dilute rather than under-dilute these formulations.

The most effective method for determining optimum dilution is to start by spray-applying the coating to the substrate at the package viscosity. If the results are unacceptable, the spray painter can dilute the coating with water in small, measured increments. At the end of each dilution, the spray painter should stir the coating well and spray-apply it. The optimum viscosity is the highest viscosity at which the coating can be applied to achieve the desired dry film thickness as well as the absence of defects such as cratering, pin holing, runs, and sags.

12.6 Problems Associated With Viscosity Mismanagement

This section illustrates why it is critical to measure and control viscosity. In the absence of proper viscosity control, numerous types of film defects can occur, often resulting in reworks and rejects. Not only is this harmful to the environment by adding to air, water, and waste pollution, but it adds unnecessarily to the cost of the finished product.

12.6.1 Effect of Film Thickness Variations on Color, Gloss, and Drying Time

Generally, spray guns can more easily atomize low viscosity coatings than high viscosity formulations. In the case of most high solids solvent-borne coatings, which tend to have relatively high viscosities, spray gun atomization becomes more difficult. This is why it is not uncommon for film thickness variations to occur when spray applying a high solids solvent-borne coating to a workpiece. Such variations are accentuated when the workpiece has a complex geometry, as is the case with many weldments and assemblies.

An observer can notice real and apparent color differences attributable to the film thickness of any coating applied to adjacent areas of a workpiece.

If the coating demonstrates some degree of transparency, then the color of the substrate may shine through in those areas where the coating film build is relatively light. If an adjacent area has a slightly heavier film build, the coating may totally obliterate the substrate and the observer notices a color difference between the two adjacent areas.

Similarly, when two adjacent areas exhibit differences in film thickness, the gloss of the coating appears different. Generally, the thicker the film, the higher the gloss. If gloss differences between adjacent areas are too pronounced, they can be a cause for rejects.

A person's perception of color is influenced by the gloss of the finish. For instance, if a spray painter applies a black coating to a panel so that one area has a high gloss while the adjacent area has a matt or lusterless finish, an apparent color difference ensues, depending on the angle at which the observer views these areas. When the observer stands in a position such that the gloss of adjacent areas cannot be seen, the color of these areas is identical. On the other hand, when the observer stands at an angle that illuminates the gloss differences, the higher gloss area tends to look a deeper and richer black, while the adjacent area looks dark grey or charcoal. Similar apparent color differences occur with other colors, but sensitivity to gloss varies for each color.

Film thickness variations also cause drying time differences between adjacent areas. Not only do the thicker films take longer to dry and cure, but other defects such as pin holing, cratering, solvent entrapment, and corrosion are more likely to occur.

12.6.2 Effect of Viscosity Differences on Metallic Colors

The application of metallic pigmented coatings is particularly sensitive to viscosity differences. Spray painters who operate in industries such as automotive and automotive refinishing must know how to manage viscosity to avoid color differences in metallic-pigmented coatings.

The luster that metallic pigments can achieve depends to a great extent on the orientation of the pigments on the top surface of the coating. Because most metallics are flat platelets, the manner in which they reflect light depends on their orientation relative to the observer. If the coating has a high viscosity, the pigments will orient themselves differently than if the coating has a lower viscosity. Even minor viscosity differences can affect the appearance of metallic colors, and for industries that require tight color tolerances, such defects are among the most common causes for reworks and rejects.

12.6.3 Effects of Too Low a viscosity

When the viscosity is too low, other problems occur resulting in rejects and reworks. For instance:

- The film thickness may be insufficient to provide proper hiding of the substrate.
- Transparency may occur particularly with pastel colors.
- Runs and sags are difficult to avoid.

- Corrosion may take place prematurely.

Each coating defect can result in reworks, rejects, and consequently more pollution and higher costs.

12.7 Strategies That Optimize Factors Affecting Viscosity

12.7.1 Effect of Plural-Component, In-Line Mixing

One of the most common sources of liquid hazardous waste in a paint facility results from surplus premixed plural-component coatings, such as epoxies and polyurethanes, that can no longer be used. A facility can often reduce the volume of hazardous waste from this source alone, sometimes by as much as 90 percent, by installing a proportioner and in-line mixer. As stated earlier, this equipment can measure the correct proportions of the unmixed components and then mix them immediately prior to their entering the spray gun.

The proportioner accurately measures or meters the two or three components only as they are about to be used (see Figure 12-8). Because the distance from the manifold to the spray gun is usually no more than a few feet, only a small amount of mixed material requires disposal at the end of the working shift.

With plural-component metering and mixing equipment the viscosity remains constant throughout the day, and pot life is no longer a concern. When selecting a plural-component system, a facility must carefully establish the accuracy of the measuring or metering mechanism. Some vendors have designed mechanical devices that proportion the components, and others use positive pressure pumps. In addition, some have alarms that sound if one of the ball valves becomes blocked either with resin or with dirt, and other design options are available.

All of the large spray equipment manufacturing companies sell at least one type of proportioning and mixing device, and each provides various options. Ease of maintenance is a critical characteristic; it is important to select equipment requiring little maintenance and having few moving parts.

Muir (5) has written extensively on the selection of plural component proportioners.

12.7.2 Effect of Dilutant (Reducer or Thinner) on Viscosity

Although pollution prevention efforts attempt to use strategies other than solvents in managing viscosity, solvent use is often unavoidable.

Each organic solvent affects the viscosity of a given resin system differently. Some solvents may be very effective in dissolving the resin, while others may be marginal, ineffective, or even harmful.

Most coating formulations contain a blend of true solvents and diluents, the combination of which are intended to provide the desired coating application properties.

A true solvent is defined as: “A substance capable of dissolving another substance (solute) to form a uniformly dispersed mixture (solution) at the molecular or ionic size level. Solvents are either polar (high dielectric constant) or nonpolar (low dielectric constant).” Water, the most common of all solvents, is strongly polar (dielectric constant 81), but hydrocarbon solvents are nonpolar. Aromatic hydrocarbon solvents have higher solvent powers than aliphatics (alcohols). Other organic solvent groups are esters, ketones, amines, and nitrated and chlorinated hydrocarbons (6).

A diluent is defined as: “A volatile liquid which, while not a solvent for the non-volatile constituent of a coating or printing ink, may yet be used in conjunction with a true solvent, without causing precipitation. An ingredient used to reduce the concentration of an active material to achieve a desirable or beneficial effect” (7).

Figure 12-9 illustrates how different solvents and diluents can affect the viscosity of one resin.

Some high solids, solvent-borne coatings are packaged with volatile organic compounds (VOCs) contents lower than the regulated limits, thus allowing the end-user to add a small quantity of reducer for viscosity management. Since many spray painters experience difficulty when applying high solids, solvent-borne coatings, they often prefer to add reducers that eliminate film defects such as that known as orange peel. When the coating can tolerate only a small quantity of solvent, the spray painters must be able to select a solvent or blend that can perform the reduction quickly. They usually prefer the solvent with the highest solubility parameters. Unfortunately, such solvents often evaporate rapidly resulting in a relatively dry coating application. The best recourse is for the operator to work closely with the coating manufacturer who can identify the most effective solvent or solvent blend without degrading the coating application properties.

12.7.3 Effect of Temperature on Viscosity

One of the most effective methods for reducing viscosity is to raise the temperature of the coating (see Figure 12-10).

The effect of temperature differs from one resin to another. For instance, a high solids alkyd, air-drying enamel might have a relatively flat viscosity/temperature curve, whereas a high solids, baking enamel may have

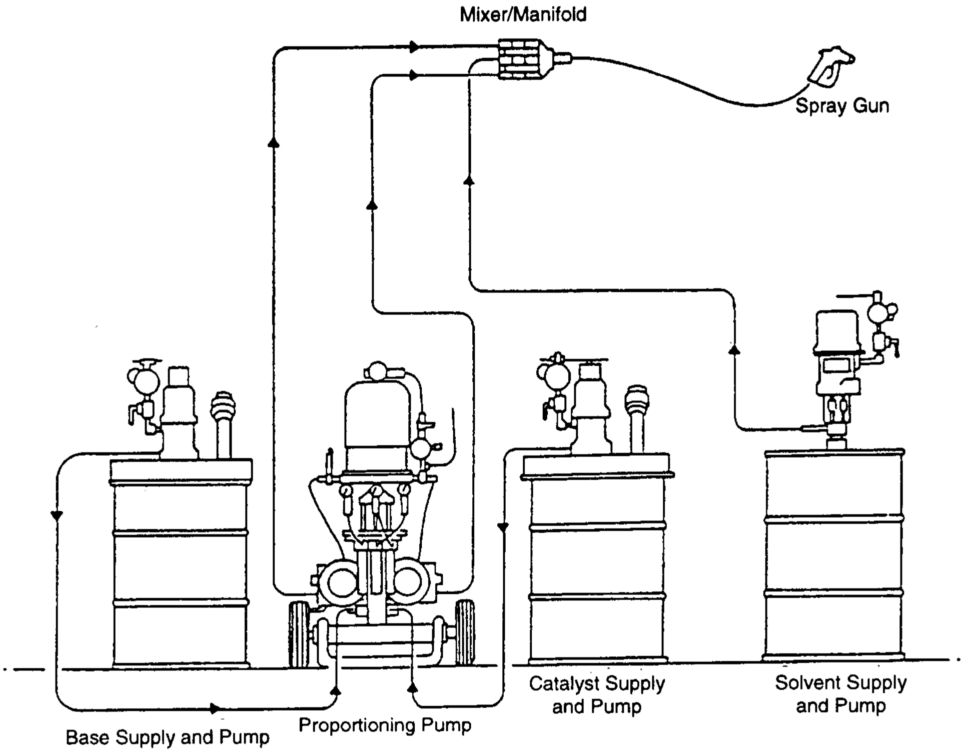

Figure 12-9. **Plural-component proportioning system (illustration courtesy of Grace Catalog publisher).**

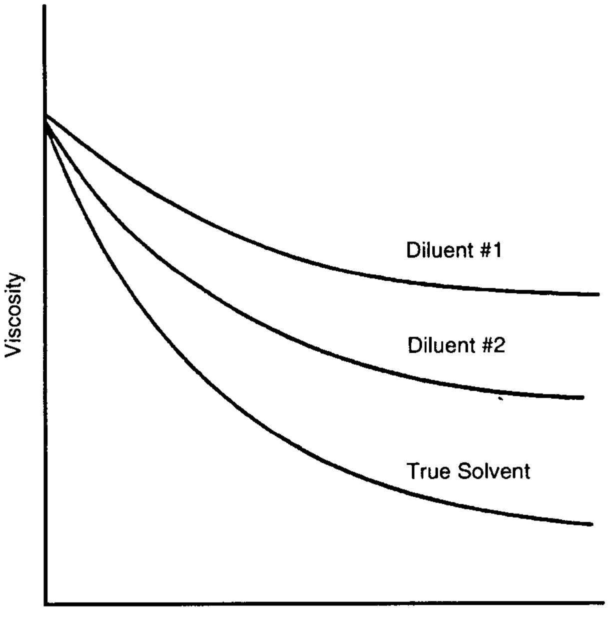

Figure 12-9. Effect of solvents and diluents on viscosity.

a curve that is much steeper. Advantages and disadvantages exist in both situations.

In the case of a flatter curve (see Coating A of Figure 12-10), small fluctuations in temperature during the working day are unlikely to markedly affect the viscosity and application properties. If there is a significant difference, however, between the early morning and late afternoon temperatures, the spray painter would notice the change.

A reasonably flat viscosity/temperature curve is advantageous to a paint facility that has no temperature controls on the spray booth air and does not want to invest in an in-line fluid heating system.

The disadvantage of a flat viscosity/temperature curve is that heating the coating by means of an in-line heating system does not offer much benefit in terms of viscosity reduction.

Contrast Coating A in Figure 12-10 with a high solids, baking enamel, such as Coating B. Here, the viscosity drops rapidly with even small temperature increases. The most important advantage of such a resin is that heating the coating to a reasonable temperature, such as 100^{o}F to 120°F, allows the operator to spray the coating at a reasonably low viscosity. In fact, it is possible that solely heating the paint eliminates any need for additional solvent reduction. Therefore, heating the coating to a reasonable temperature can be a very effective strategy for lowering VOC emissions.

The disadvantage of a steep viscosity/temperature curve is that small temperature fluctuations can make noticeable difference on the application of the coating. Facilities that struggle to maintain coating quality may find that the primary cause for coating finish differences is the major and minor temperature fluctuations that take place during a normal working day.

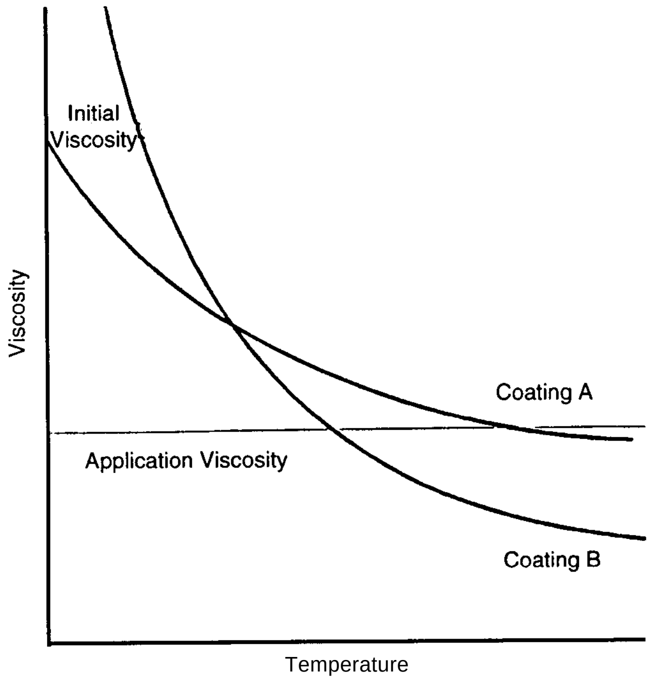

Figure 12-10. Effect of temperature on viscosity.

Control of coating temperature for single-component coatings is usually cost-effective because less solvent, if any, is necessary for viscosity reduction, and coating defects and rejects are minimized.

12.7.3.1 In-Line Heating

Paint heaters are available in various designs. In some, the coating comes into contact with a heating element. In others, heat transfer takes place between a heated fluid, such as water or an oil, and the coating. In at least one other design, the heated fluid travels through the outer annulus of a coaxial fluid hose, while the coating travels through the inner core.

Although the first design might be the least expensive, its most important disadvantage is that if the coating does not constantly circulate through the fluid hose, hot spots can occur where the coating remains in contact with the heating element for more than a few seconds.

In order to ensure constant temperature throughout the day, regardless of whether or not the spray gun is being triggered, the equipment should be fitted with a return loop so that heated coating that flows to the gun has an opportunity to flow back to the heater upon release of the trigger. Moreover, the loop should go back only to the inlet to the heater rather than all the way back to the pressure pot or coating reservoir. No need exists to heat the coating in the hose between the reservoir and the heater, nor does the coating in the reservoir itself require heating as this unnecessarily consumes energy and results in solvent losses from the open portion of the system. To minimize the volume of coating that needs heating, the in-line heater can be located close to the spray gun, on the wall of the spray booth. This way, the only coating that requires heating is the volume in the fluid hose between the heater and the spray gun, and in the return hose.

Facilities that require absolute consistency in color, gloss, and film thickness should insulate the fluid hose between the heater and the spray gun. This is because, as Figure 12-10 shows, even slight fluctuations of temperature can cause noticeable viscosity differences, particularly with high solids baking coatings.

Many end-users try to save money by purchasing dead-end heating systems. This means that the fluid hose from the heater to the spray gun does not return back to the heater. While this may save a few dollars in initial capital expense, every time the spray gun is left untriggered, the temperature in the hose from the heater to the spray gun drops resulting in a corresponding viscosity increase. Then, when the operator pulls the trigger, the coating in the fluid line between the heater and the spray gun has a higher viscosity than the coating that emerges from the heater. This results in uneven finishes and other defects, which of course leads to rejects and waste. The cost to convert a dead-end system into a recirculating one is expected to be minimal.

12.7.3.2 In-line Heating of Plural-Component Coatings With Metering and Mixing Equipment

As was discussed earlier, the use of in-line heaters for premixed plural-component coatings is not recommended because this leads to very short pot lives. When using plural-component proportioners and mixers, however, in-line heaters are beneficial because the coating is mixed only a few seconds prior to application. Thus, it is possible to lower the viscosity of the individual components, even if the mixed coating would otherwise have **a** high viscosity.

Once again, heating a mixed plural-component coating dramatically shortens its pot life. As a result, the fluid hose from the mixer to the spray gun, and the gun itself must be flushed clean before the coating has an opportunity to gel! If the operator does not follow this procedure, the fluid hose and spray gun may need to be discarded.

12.7.4 Effect of Batch Mixing of Plural-Component Coatings

Chapter 10 included a detailed explanation of pot life, which results when plural-component coatings are mixed together. Figure 12-11 illustrates the viscosity increase that takes place soon after mixing occurs and cross-linking commences.

For a single-component coating, provided that the temperature remains constant throughout the day, the viscosity also remains constant. On the other hand, for a plural-component coating, the viscosity gradually rises within the first few hours after mixing. Thereafter, it increases rapidly until the coating gels. The time that elapses after the coating has been mixed and until the spray painter can no longer apply the coating to achieve an acceptable finish, is known as the pot life. For some plural-component coatings, the pot life can be as long as 8 to 16 hours, while for some of the more reactive systems, it can be less than 2 hours. A few new high solids, two-component technologies possess pot lives as short as a few seconds. These require special mixing equipment.

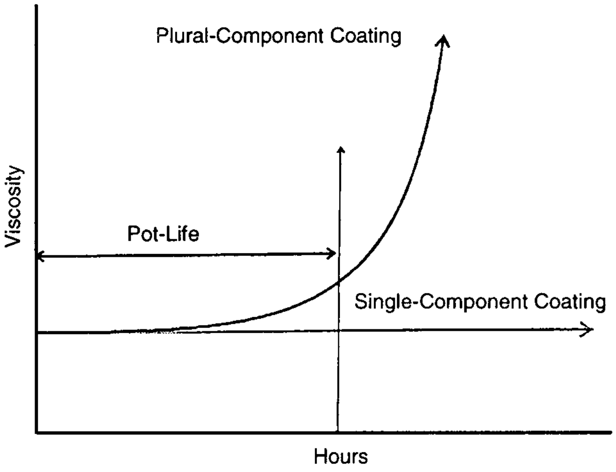

Figure 12-11. **Effect of viscosity on single- and plural-component coatings.**

Bear in mind that even when controlling the spray room temperature, the coating temperature can rise due to the exothermic chemical reaction that takes place.

While Figure 12-11 assumes that the coating remains at a constant temperature, Figure 12-12 illustrates how rapidly pot life can accelerate when the temperature increases. Clearly, two counteracting processes take place when the temperature of a plural-component coating increases. First, higher temperatures tend to lower the viscosity of resin systems, and this is beneficial when high viscosity coatings require spray application to achieve acceptable finishes. Second, an increase in temperature accelerates cross-linking, which in turn shortens the pot life.

A facility may find itself wondering which of the two mechanisms it should be more concerned with. If the viscosity of the coating is allowed to increase well beyond the pot life, the coating would gel and plug the fluid line and spray gun. Frequently, the cost and effort required to clean out the fluid passages is higher than the cost to simply replace the equipment. This is why when using plural-component coatings, the general rule is to maintain as low as practicable a coating temperature. Usually, this is ambient, but in cases where the spray booth warms up during the working day, it is not uncommon to wrap the reservoir with an insulating blanket to prevent a corresponding increase in coating temperature.

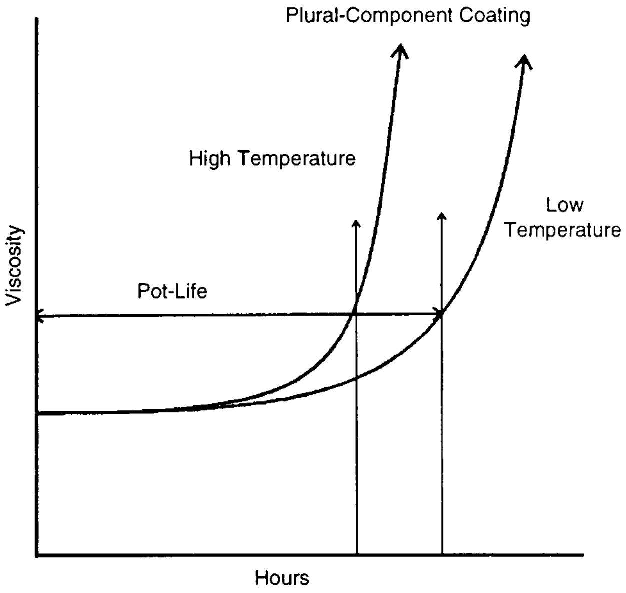

Figure 12-12. **Effect of temperature on pot-life of plural-component coatings.**

12.7.5 Methods for Increasing the Pot-Life of Batch-Mixed Plural-Component Coatings

The most effective method for increasing the pot-life is to maintain the mixed coating at a cool temperature, but not so cold as to allow condensation of moisture to take place. The mixed coating should not be placed in a refrigerator because moist air in the head space above the level of the mixed coating may condense and cause gel particles to form within the body of the coating.

If the container or reservoir has no head space and the coating is filled to the top, then placing the mixed coating into a refrigerator can prolong its pot-life. Before opening the container again, however, allow the temperature of the coating to increase to approximately ambient conditions to prevent condensation of the outside air from settling on the surface of the coating.

Another method to increase pot-life involves constantly agitating the mixed coating, but at a slow speed rather than too vigorously. The coating should not be agitated by bubbling compressed air through it because moisture in the air can react with the coating's curing agent, once again promoting gelation.

The curing agents of many plural-component coatings, particularly polyisocyanates, are sensitive to moisture. If the reaction between the moisture and the curing agent is allowed to take place, the viscosity rapidly increases until the polymer gels. To prevent this, replace the air in the head space above the curing agent with either a nitrogen blanket or pass the air in the head space through a desiccant.

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Chapter 13
Minimizing Solvent Usage for Equipment Clean-Up

13.1 Introduction

13.1.1 Pollution Prevention Considerations

Solvents are used in various parts of a coating facility, including:

- Vapor degreasing
- Solvent wiping of substrates prior to painting
- Reducing paints and coatings to adjust viscosity
- Clean-up of spray equipment

Earlier chapters covered in depth the strategies for minimizing solvent use through different pretreatment factors as well as application process factors. This chapter focuses primarily on minimizing the use of solvents for the clean-up of spray application equipment, and for other miscellaneous purposes.

Most facilities that use solvent-borne coatings find that their liquid hazardous waste comprises mainly the solvents they use to clean the fluid hoses, pressure pots, and spray guns. The solids content of liquid hazardous waste from a paints and coatings facility is often as low as 10 to 15 percent. This means that 85 to 90 percent of the liquid hazardous waste is a mixture of solvents.

Most state volatile organic compounds (VOCs) regulations require that solvents used for equipment clean-up must be stored in closed containers. In addition, the regulations mandate that facilities clean the spray guns within an enclosed container. The purpose of these provisions is to minimize solvent evaporation during equipment clean-up. As a consequence, the industry generates large volumes of spent solvent-paint mixtures that are usually stored in 55-gallon drums.

Facilities can incorporate strategies for utilizing and minimizing waste solvent. The strategies that this chapter discusses are:

- Recycle solvents
- Minimize emissions of hazardous air pollutants (HAPs)
- Follow regulatory provisions

13.1.2 Decision-Making Criteria

Decision-making criteria relevant to minimizing solvent usage for clean-up, as addressed in this chapter, are highlighted in Table 13-1.

13.2 Solvent Recycling

A facility may use a solvent distillation unit to boil off the solvents, and then condense them in a clean 5-gallon pail or 55-gallon drum. Figure 13-1 shows a typical distillation unit.

The distillation units that paint facilities use are usually explosion-proof. They consist of a large permanent container with a tight-fitting cover. Heating coils surround the outside of the container. At the end of a shift, or whenever appropriate, the painter pours or pumps the mixture of waste solvent and paint into the container, closes the cover, and turns on the heating element. As the temperature rises, the most volatile solvents start to evaporate off into a long condensation coil. A refrigeration unit cools the coil, and as the solvents pass through the coil they condense into clean liquid solvent. A hose at the end of the coil transfers the condensed solvent into a 5-gallon pail or 55-gallon drum. As the temperature in the unit continues to climb, less volatile solvents start to evaporate and subsequently condense. This process continues until approximately 85 to 90 percent of the waste solvent/paint mixture evaporates and condenses.

The sludge remaining at the bottom of the unit is a very high concentration of the paint solids. Typically, this only accounts for 10 to 15 percent of the original volume, and this, together with the polyethylene bag that contains it, is disposed of as solid hazardous waste.

The facility can re-use the clean collected solvent as a clean-up solvent. Because the solvent mixture might contain a different blend of solvents from that used in the formulation of the coatings, it is not common to use the condensed solvent as a reducer for the coatings. One other approach is to sell the waste solvent to a solvent blender or a facility that can use the solvents as fuel.

Solvent distillation units are available in all sizes, from less than 5 gallons to 55 gallons. Names and addresses

Table 13-1. Decision-Making Criteria Regarding Minimizing Solvent Usage for Equipment Clean-Up

issue	Considerations
Does the facility send large volumes of solvent-borne paints as well as reducing and clean-up solvents out as waste?	• If yes, consider installing a solvent distillation machine that would allow for the on-site recovery of solvents; first, however, fully investigate the hazardous waste regulations that concern on-site solvent recovery and recycling. • If distilling on-site is not possible, consult with a solvent recycling company to see if it is worth having the company perform your recycling.
Are any of the solvents used in the facility HAPs or ODCs?	• If yes, consider finding alternatives because most solvent companies now offer solvent blends that have excellent solvency but contain neither HAPs nor ODCs; for some applications, you may find solvents that are not VOCs, HAPs, nor ODCs.
Does the facility's potential to emit solvents cause it to exceed a threshold for Title iii and/or Title V?	• If yes, find alternatives that would allow the facility not to exceed this threshold; the cost benefit to the company is usually well worth the effort.
Has the facility checked to see if the solvents it is using have high-boiling points?	• If not, ensure this is done because it may be possible to substitute some of the more volatile (lower boiling) solvents with ones that have higher boiling points and evaporate more slowly.
Do the operators clean the spray guns and fluid hoses by atomizing solvent through the spray guns?	• If yes, check local regulations because this is now an air pollution violation in many states. • Consider flushing the hoses and guns by spraying a stream of solvent (not atomized) directly into a 55-gallon hazardous waste drum, and immediately replacing the lid.

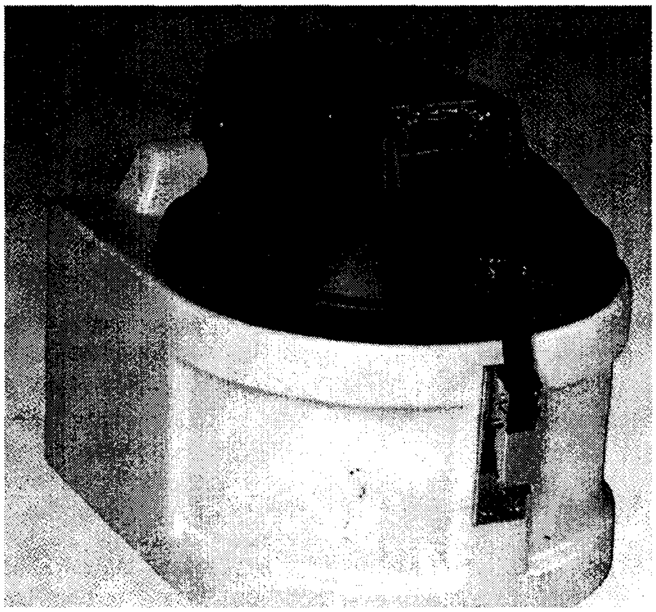

Figure 13-1. Typical solvent distillation unit (illustration courtesy of Siva, a division of Flair Environmental).

of vendors appear in the annual buyers' guides that the major coatings journals publish annually.

Joseph (1) has described the permitting requirements and alternatives for dealing with solvent recyclers. Because the issue is complex, readers should delve further into the matter with their local state agencies or legal advisors before making a decision to install such equipment.

In the absence of a solvent distillation unit, a facility can reduce the cost of hazardous waste disposal by segregating the wastes. Water-borne paints, and any other water-borne products, should not be mixed with the solvent wastes. Papers, masking tape, waste cups, rags, etc., should also be segregated and not dumped into the solvent waste drums. While the overall volume of waste remains the same, by segregating, the facility can minimize the volume of waste it needs to send to a hazardous waste disposal site. Some of the other wastes might be able to go to a landfill. The potential costs reductions for such segregation are well worth the effort.

13.3 Minimizing Emissions of Hazardous Air Pollutants

Title III of the Clean Air Act Amendments of 1990 (40 CFR Part 63) lists solvents considered to be hazardous air pollutants (HAPs). The following list includes the most common HAP solvents found in paints and coatings formulations, as well as in clean-up solvents:

- Methylethylketone (MEK).
- Methylisobutylketone (MIBK).
- Toluene.
- Xylene(s).
- 1,1,1 Trichloroethane (also an ozone depleting compound, or ODC).
- Methylene chloride.

Title III lists many other solvents and chemicals used in paints and coatings formulations but they generally appear in smaller quantities. To determine whether a coating formulation contains one of these HAPs or ODC's, refer to the Material Safety Data Sheet (MSDS) that is submitted with every delivery of paints and solvents.

While paints and coatings facilities can still use these solvents in the foreseeable future, stringent air quality regulations encourage facilities to find substitutes. If substitutes are not possible, facilities must try to establish measures for minimizing their emissions into the air.

Both Title III *"Hazardous Air Pollutants"* and Title V *"Permit Operating* Rule" (40 CFR Part 70) require a major facility to comply with their regulations. A major facility is one that has the potential to emit more than 10 tons per year (tpy) of any one HAP, or more than 25 tpy of a combination of HAPs, and some states may decide to lower these thresholds. Title V also considers a facility to be major if its emissions of VOCs are more than 100(tpy).

The definition of potential to emit is complex, so a facility should seek clarification from its local air pollution agency. Even a facility that does not use large quantities of paints and solvents may have a potential to emit over the threshold levels. Because the definition of "major" from above covers only some of the requirements from Titles III and V, each company should refer to both regulations to determine all of the criteria that might affect it. Both Basset (2) and The Air Pollution Consultant (3) provide excellent sources for understanding the implications of these regulations.

13.3.1 Strategies To Minimize HAP Emissions

13.3.1.1 Using Substitutes

Facilities that want to minimize their HAP emissions can ask their coating vendors and solvent suppliers to use substitutes where such exist. Substitute solvents, however, may affect the viscosity, drying time, and flow-out characteristics of the coatings. Substitute solvents used for clean-up of equipment may not be as efficient as the original solvent blend. Therefore, tests must ensure that the compromises being made are acceptable to the paint facility. If compromises are necessary, the facility should balance them against the difficulty of having to comply with strict and possibly cumbersome Title III or Title V regulations.

13.3.1.2 High-Boiling Solvents

High-boiling solvents evaporate slower than those with a lower boiling point. Thus, if an operator is cleaning spray equipment, he has a greater opportunity to capture dirty solvent before it evaporates. Therefore, in formulating a blend for clean-up purposes, a facility should consider one or more of the solvents listed in Table 13-2.

Table 13-2. High-Boiling Solvents (4, 5)

Solvent Type	Boiling Range	
	°F	°C
Hydrocarbon Solvents:		
Hi flash VM&P Naphtha	260 - 288	126 - 142
VM&P Naphtha	244 - 287	118 - 140
Mineral spirits	307 - 389	153 - 198
Odorless mineral spirits	354 - 388	179 - 198
Stoddard solvent	308 - 388	154 - 197
Aromatic Hydrocarbons:		
Toluene[a]	230 - 232	110 - 111
Ethyl benzene	275 - 277	135 - 136
Alcohols:		
Isobutyl alcohol	223 - 229	106 - 109
n-Butyl alcohol	243 - 245	117 - 119
Ketones:		
Methylisobutylketone (MIBK)	237 - 244	114 - 117
Methyiisoamylketone (MIAK)	287 - 297	141 - 148

[a] On the EPA 33/50 list as a hazardous air pollutant.

13.3.1.3 Example Blend: Ashland Chemicals

Ashland Chemicals has provided one blend of clean-up solvent that has worked well for alkyds, epoxy, and polyurethane coatings, including chemical agent resistant coatings (CARC). The blend's formulation follows: VM&P naphtha (40%) methanol (20%), acetone (15%), n-butyl acetate UG (15%) and isobutyl alcohol (10%).

Note that none of the solvents in the blend is either an HAP or an ODC. In addition, this formulation is not unique or proprietary to Ashland and can be formulated by any solvent distributer.

13.4 Regulatory Provisions

State regulations regarding paints and coatings exist in the interest of preventing pollution. These regulations act as necessary and useful guides for facilities seeking to minimize the environmental impact of their solvent usage for clean-up purposes. Surface coating regulations in several states have provisions similar to those in California. The following example comes from California's South Coast Air Quality Management District rule for the painting of metal parts and products.

13.4.1 South Coast Rule 1107, (b)(3-7)

A person shall not use VOC-containing materials for the clean-up of equipment used in coating operations unless:

- The VOC is collected in a container which is closed when not in use and is properly disposed of, such that the VOC is not emitted into the atmosphere; or

- The spray equipment is disassembled and cleaned in a solvent vat, and the vat is closed when not in use; or
- The clean-up materials contain no more than 200 g/L of VOC per liter of material.

13.5 Process for Cleaning Spray Guns and Fluid Hoses

When considering the clean-up of equipment, one should bear in mind that all organic solvents have a VOC content well above 200 g/L, but the regulation implies that the organic solvent can be mixed with water or with an exempt solvent. Because the most common exempt solvent is 1,1,1 trichloroethane, which is both an HAP and an ODC, the end-user should use caution in using this option. Because of its status as an ODC, use of this solvent is gradually being phased out.

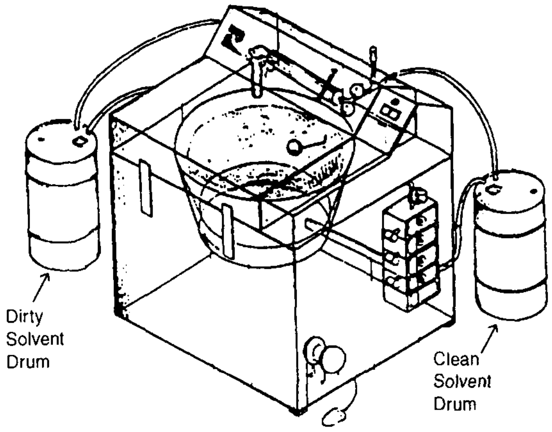

Figure 13-2. Typical spray gun cleaner (illustration courtesy of Siva, a division of Flair Environmental).

Spray gun cleaners are available in many different designs but, in essence, they perform much like cold cleaning tanks. Figure 13-2 shows a typical spray gun cleaner.

A gun cleaner essentially comprises an enclosed solvent tank. A door or lid allows access inside. The operator attaches the fluid hose of the spray gun to a fluid hose within the tank. Upon closing the door or lid, solvent pumps through the fluid hose of the gun. The operator can remove the clean gun after a few seconds. When not in use, the door or lid of the cleaner must remain closed.

When using an air atomizing or HVLP spray gun, a common method for flushing coating from the fluid hose of the gun back into the container or reservoir is as follows:

- Turn down the fluid pressure from the reservoir but keep the valve open.
- Set the air pressure to the gun at approximately 40 psi or more.
- Hold a cloth tightly in position in front of the gun air cap, and pull the gun trigger.
- The air, which cannot escape from the cap, enters the fluid hose and forces the coating in the hose all the way back to the reservoir.
- After the coating returns to the reservoir, use a small quantity of solvent to clean the inside of the hose.

This technique is very effective in dramatically reducing the quantity of solvent required. The following cautionary note, however, must be read!

> Note: Under no circumstances must the technique for back-flushing coating to the reservoir be used when air-assisted or airless spray guns are being used.
>
> Airless guns do not have an air hose. If the spray painter holds his hand in front of the gun orifice and then pulls the trigger, the coating can be injected through the painter's skin. This will result in serious injury and hospitalization.
>
> Even though air-assisted airless guns have an air hose, the fluid pressure for these guns can also cause harm to the painter. As a result, the technique for back-flushing the coating into the pressure pot also must not be carried out with this gun.

When cleaning an air-assisted airless gun, the compressed air regulator should be closed to prevent unnecessary atomization when the trigger is pulled. The fluid orifice of both the air-assisted airless and the airless spray guns should be removed before pulling the trigger. The operator, however, must be cautious when removing the orifice for the reasons described in the note above. The operator should point the gun into a grounded 55-gallon solvent waste drum and then pull the trigger to flush solvent through both the fluid hose and the fluid passage of the spray gun.

For maintenance of pressure pots, many companies provide pressure pots with a polyethylene inner liner. This is advantageous because the paint comes into contact with the liner rather than with the steel or stainless steel body. Cleaning the liner requires only a small quantity of solvent. After pouring it into the liner and swirling it around for a few seconds, the operator can discard the dirty solvent into a 55-gallon hazardous waste drum. The inner liner can then be reused.

Some operators choose to allow the paint that sticks to the side of the liner to dry out, which causes it to flake off with ease. If the solid paint is shown to be hazardous per EPA guidelines, it will be disposed of as solid hazardous waste. If dry paint is shown to be non-hazardous, it might be discarded to a landfill. Again, the liner can be re-used.

Regarding conventional air-atomizing, HVLP, and air-atomizing electrostatic guns, special spray gun hose cleaners are available from spray equipment manufacturers. These force a mixture of air and solvent turbulently through the fluid hose. The turbulence is effective in efficiently flushing the coating from the hose, whereas only a small quantity of solvent is required. Some equipment vendors, however, have withdrawn their products from the market because they felt that the turbulence atomized the solvent which could not then be collected for reuse. The end-user must experiment to determine whether or not such a device would minimize solvent emissions into the air.

13.6 References

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Chapter 14
Paint Stripping: Alternatives to Solvent-Based Methods

14.1 Introduction

14.1.1 Pollution Prevention Considerations

Paint stripping is a process stage common to paints and coatings operations. Although efficiently run operations attempt to minimize the need for paint stripping, the need can still arise for workpieces either because the applied coating is defective, the job specifications have changed, or the original coating has aged. Occasionally, process equipment (e.g., racks, vessels, booths, and grates) also must undergo paint stripping to remove the buildup of overspray.

Historically, operations relied extensively on chlorinated solvents (e.g., primarily containing methylene chloride) to remove coatings because formulations were inexpensive to use and their effectiveness well established. Reliance on such approaches has become more expensive, however, due to the cost of managing wastewater contaminated with toxic chemicals and controlling the release of volatile organic compounds (VOCs).

For a number of years, operators-especially in the automotive and heavy equipment industries-also have been using aqueous paint stripping products where appropriate. These formulations generate less pollution because they are based on a relatively small amount of organic solvent, but they are effective on a-narrower range of coatings. The relatively new semi-aqueous products, formulated with water and a nonchlorinated solvent, await more extensive use in industrial operations to demonstrate apparent advantages (e.g., pollution reduction and effectiveness on resistant coatings).

In the meantime, an array of alternative approaches involving "cleaner" technologies are gaining wider use in paint stripping operations. These methods are considered cleaner because they rely on physical mechanisms of action for coating removal rather than chemical solvents. As a result, when used in appropriate industrial applications, these approaches can help operators minimize pollution generation, and thereby hold down associated process costs.

Although these newer approaches offer important pollution prevention opportunities, the broad application of any single method is unlikely. That is, rather than one coating removal technology replacing solvent strippers in all applications, operators will need to assess technologies on a process-specific basis. The appropriateness of a technology for a particular facility will depend on factors that include the type of coatings to be removed and the nature of the workpieces' substrate.

Alternative technologies are discussed in this chapter in the context of pollution prevention and process efficiency considerations.

14.1.2 Decision-Making Criteria

Decision-making criteria relevant to the use of alternative paint stripping approaches, as addressed in this chapter, are highlighted in Table 14-1.

14.2 Process Basics

Paint stripping operations generally are conducted when a previously applied coating on a substrate must be removed. Usually paint is stripped from workpieces in preparation for recoating. In some cases, however, metal workpieces and parts undergo surface polishing instead of painting (e.g., polished aluminum used for some components in aircraft); thus, when appropriate, one pollution prevention approach is to avoid the need to apply a coating in the first place.

Paint stripping is a stage in most paints and coatings processes even at facilities where best management practices are closely adhered to throughout the operation. This process step may be necessary for any of the following reasons:

- Defects are detected in the finished piece.
- Specifications change after finishing (e.g., color, performance requirements).
- A workpiece's original coating has aged.
- Paint has built up on production line equipment from overspray (e.g., conveyor hooks and racks, spray booth grates).

The decision whether to rework or scrap workpieces calls for assessing the value of the particular piece in regard to

Table 14-1. **Decision-Making Criteria Regarding Paint Stripping Operations**

Issue	Considerations
Are workpieces currently being stripped using a methylene chloride product?	• If so, consider the appropriateness of switching to "cleaner" paint stripping technologies that generate less pollution.
Are the workpieces high-cost items with high-performance specifications (e.g., aircraft components), requiring that critical tolerances not be altered by processing?	• If so and the workpieces cannot be subjected to extensive contact with water, consider plastic media blasting, wheat starch blasting, or carbon dioxide pellet cryogenic blasting. • If so and the workpieces can be subjected to contact with water, consider high- or medium pressure water blasting or sodium bicarbonate wet blasting.
Must paint coatings be stripped from workpieces selectively (e.g., remove only the topcoat) or removed from delicate substrates?	• If so, consider wheat starch blasting, sodium bicarbonate wet blasting, high-pressure water blasting, or carbon dioxide pellet cryogenic blasting.
Are the workpieces assemblies that include machined surfaces and moving parts, and thus cannot be subjected to extensive contact with water or to a small media that can become entrapped by components?	• If so, consider carbon dioxide pellet cryogenic blasting.
Are the items to be stripped process-related equipment (hooks, grates, baskets) coated with overspray?	• If so, consider medium-pressure water blasting, burnoff, molten salt bath stripping, or liquid nitrogen cryogenic blasting.

the number of pieces in the lot and the cost of reprocessing. For all but the simplest and cheapest items, reworking usually proves more cost effective than disposal.

As discussed in this chapter, paint stripping can be conducted by various means. The conventional approach involves the application of a chemical solvent. Traditional formulations are based on methylene chloride (60 to 65 percent), which penetrates the coating causing it to swell and separate from the substrate. This approach, however, generates organic vapors, which raise concerns about threats to worker health and about damage to the ozone layer of the atmosphere, as well as considerable sludge and wastewater laden with solvent. Aqueous and semi-aqueous paint stripping formulations, with smaller percentages of chemical content, also are available. Although, these less-concentrated chemical formulations minimize pollution concerns, drawbacks can include high cost, limited applicability, and slower and less-thorough performance.

As a result, industry and government have been conducting extensive research into the development of paint stripping methods whose performance relies less on solvents. Alternative approaches under development or already in use involve on one or more of the following general mechanisms of action:

- Impaction. Breaking up the coating by subjecting the workpiece surface to a flow of grit material (media) delivered at high velocity.
- *Abrasion.* Wearing away the coating by scouring the workpiece surface with a rough material; some media delivered at high velocity have a scouring effect.
- *Thermodynamics.* Oxidizing, pyrolizing, and/or vaporizing the coating by subjecting the workpiece to heat.
- *Cryogenics.* Releasing the bond between the coating and the substrate by subjecting the workpiece to extreme cold, making the coating friable and inducing differential contraction.

One abrasion approach, media blasting, is also used to clean corrosion and other contaminants from uncoated metal workpieces before applying a primer-topcoat system, as discussed in Chapter 8 (on abrasive blast cleaning).

The various alternative approaches discussed in this chapter are considered "cleaner" in terms of pollution generation because their performance is based on physical mechanisms rather than solvents. These approaches also have their drawbacks. The information provided is intended as a brief introduction to each technology; for more detailed information, see EPA's *Guide to Cleaner Technologies: Organic Coating Removal* and EPA's *Reducing Risk in Paint Stripping: Proceedings of an International Conference* (References 1 and 2, respectively).

Before adopting an alternative paint stripping approach, the facility operator must fully consider the associated tradeoffs in respect to the specific paints and coatings operation. Factors to consider include:

- Workpiece characteristics (e.g., size, substrate)
- Coating composition
- Surface specifications for the stripped substrate
- Processing rate
- Facility space and process compatibility considerations

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[1] The material presented in this chapter **draws extensively from both** of these **EPA documents. Information is also available** on the Internet; see, for example, the U.S. department of Defense's library home page (http://clean.rti.org/larry/nav.in.html) or EPA's Envirosense home page (http://es.inel.gov). Detailed information on particular approaches also may be available from industry groups and trade associations.

- Pollution/waste generation
- Costs (i.e., capitol and operating)

14.3 Solvent-Based, Aqueous, and Semi-aqueous Methods

As described in this section, three conventional approaches to paint stripping involve the use of chemical solvents in varying amounts. Given the increasing cost and regulatory constraints associated with traditional solvent-based approaches, more facility operators are assessing expanded application of aqueous methods and examining the potential advantages of semi-aqueous products. This discussion briefly considers these three methods of coating removal. The section that follows reviews a selection of more recently developed approaches that place particular emphasis on pollution prevention-the so-called cleaner technologies.

14.3.1 Solvent-Based Methods

Most paint stripping is conducted by immersing or spraying workpieces with an organic solvent-based formulation. The solvent penetrates the coating and undermines its bond with the substrate, as indicated by wrinkling, bubbling, and blistering on the surface of the piece. The softened coating and solvent sludge are then wiped, scraped, or flushed away from the substrate. Often a workpiece must undergo this process step several times before the coating is completely removed. After coating removal, the piece usually undergoes a water rinse.

In general, solvent is only sprayed on workpieces if they are too large for immersion or if they are assemblies with sophisticated components that could be damaged by extensive contact with the solvent. If only very specific areas of an assembly need to be reworked, then the solvent may be wiped onto the appropriate surfaces. Additionally, if only a small number of pieces need to be reworked, spraying might present a more cost-effective approach than installing an immersion stripping line.

The most widely used paint stripping products are formulated with methylene chloride (also known as dichloromethane [DCM]). Although these chlorinated solvents are effective, versatile, and relatively economical, their use results in the release of VOCs, which are becoming the focus of increasing regulation under the Clean Air Act Amendments. In particular, EPA has identified paint stripping operations as a hazardous air pollutant (HAP) source category. As a result, such operations might eventually be required to implement Maximum Achievable Control Technology.

Additionally, solvent-based methods generate sludge and wastewater that contain toxic chemicals. Disposal procedures required under the Resource Conservation and Recovery Act (RCRA) and recordkeeping requirements under Section 313 of Title III can increase the cost of managing such wastes.

Nonchlorinated solvents represent another broad category of paint stripping products. These solvents, which are based on such diverse chemicals as N-methyl pyrollidone, various glycols or glycol esters, and dimethyl sulfoxide, are used almost exclusively in immersion paint stripping operations. Although these solvents allow facility operators to avoid concerns about VOCs and minimize the generation of sludge with toxic constituents, nonhalogenated products tend to be considerably more expensive than methylene chloride formulations. Additionally, immersion baths of nonhalogenated solvents must be heated (from 140^o to 250°F) to speed up their performance capabilities, which adds to operational costs. Even when heated, however, nonhalogenated solvents have a somewhat selective chemical action and thus tend to be used in a narrower range of applications than methylene chloride solvents.

14.3.2 Aqueous Methods

Stripping paint with aqueous products is a well-established methods for use in industrial operations processing metal workpieces. Although aqueous products are water based, formulations generally include some amount of an organic solvent. The most widely used aqueous strippers have a caustic component. A typical formulation might include water, 10 to 20 percent sodium hydroxide, up to 20 percent organic solvent, substantial amounts of surfactants (which are caustic, stable, surface-active agents), and a chelating agent.

Caustic aqueous strippers are primarily used in immersion processes. Immersion baths are heated (from 180- to 240°F) to accelerate the performance of the active agents in such formulations. In most operations, immersion is followed by a water rinse step.

Historically this type of aqueous paint stripper was widely used in the automotive and heavy equipment industries. The use of aqueous products in these industries has declined over the years, however, as more resistant coatings have been introduced. Aqueous strippers are still used in many operations that process home appliances and are used generally to clean process equipment. Formulations that include sulfuric or chromic acid also are in use, but for more selective applications.

As with nonchlorinated solvents, because aqueous formulations must be heated to enhance their performance, using them can add to operating costs. Also, although they minimize pollution generation issues, aqueous products are effective on a limited range of coatings and can be used only on ferrous metal and magnesium substrates.

14.3.3 Semi-aqueous Methods

Semi-aqueous products, which include water and a nonchlorinated solvent in roughly equal amounts, are relatively new and thus not yet in wide use. Such products are attracting considerable interest, however, based on indications that they are effective for stripping even the most resistant aircraft and aerospace paints. Another attraction is that they can be used in both spray and immersion process lines. Also, sludge and wastewater generated by this approach are considered relatively easy to manage because they are generally free of toxic components (e.g., chrome, phenol).

Drawbacks of this approach include the higher cost of semi-aqueous products and the longer time required to achieve desirable performance.

14.4 “Cleaner” Technologies: Alternatives to Conventional Methods

This section briefly describes a selection of alternative paint stripping approaches and lists their respective advantages and potential drawbacks. Approaches are presented according to their mechanism of action. It is unlikely that any one of these approaches will offer a broadly applicable means of stripping coatings in industrial processes. Nonetheless, facility operators should consider such cleaner technologies when developing a strategy for minimizing pollution generation. A number of newer approaches not covered in this document also show promise for reducing process-related pollution in paint stripping operations. Certain of these emerging technologies in particular are promising and thus bear watching, including laser heating, flashlamp heating, and ice crystal blasting. (For information on these methods, see Refs. 1 and 2.)

14.4.1 Impaction Methods

14.4.1.1 Plastic Media Blasting

Plastic media blasting (PMB) is an impaction method that is capable of removing a coating without damaging the substrate of a delicate workpiece. The approach involves projecting plastic media at a workpiece’s surface either pneumatically with a hose-and-nozzle system (usually in manual operations) or centrifugally from rotating wheels (in automated operations within a cabinet). After the coating has been removed, the workpiece is vacuumed or subjected to high-pressure air to remove residual plastic dust. Because PMB is a completely dry process that relies on a nontoxic media to remove coatings, no wastewater or VOCs are generated.

In most applications, the plastic media are collected and cleaned, using an air cyclone or vibrating screens, and then reused several times before being discarded. Depending on the particular coating being removed, however, debris cleaned from the media may contain hazardous metals or unreacted resins that require special handling. In general, spent media are not recyclable or biodegradable, although research is being conducted on beneficial approaches to managing spent media.

The PMB approach has been widely used in both the military and commercial sectors. While PMB is sufficiently sensitive to selectively remove individual coating layers, with larger and harder media this approach also can be used to remove such resistant finishes as polyurethane and epoxy coatings. The PMB method is applicable for metal substrates as well as plastic surfaces. PMB is used in the aerospace industry to remove coatings without damaging sensitive underlying substrates (e.g., the aluminum skins of aircraft).

Key advantages of the PMB approach include:

- *Minimizes pollution generation.* Avoids generation of wastewater and VOCs.
- *Recyclability* If the correct plastic media is selected, they can be recycled up to 30 times.
- *High throughput.* Can be effective at a higher coating removal rate than is possible using some solvents.
- *Broad applicability* For example, it can be used on steel, aluminum, plastic, fiberglass, glass, printed circuit boards, and aluminum clad materials.
- *Sensitivity* Avoids damaging substrates or altering the dimensions of critical components; can remove individual coatings.
- *Limited masking required.* Less than for other conventional stripping processes, such as chemical stripping or sand blasting.

Principal limitations of the PMB approach include:

- Conventional sand or grit blasting can be faster.
- Less effective than other methods for cleaning process equipment with a heavy buildup of coatings.
- Less effective than other methods for removing rust and corrosion from metals.
- Larger and harder media can damage plastic and composite substrates.
- Contaminants remaining in the recycled media can damage substrates.
- Capital and startup costs can be higher than for conventional abrasive blasting.

14.4.1.2 Wheat Starch Blasting

Wheat starch blasting is an impaction method that involves use of generally the same techniques and process equipment as PMB. The principal distinction between these two methods is the blast media: Wheat starch is even more gentle than plastic. Additionally, because wheat starch is 100 percent carbohydrate, the spent media is biodegradable. Using aerobic waste management processes, the media can be digested into a liquid that can then be separated from the coating debris. Also, wheat starch is a renewable agricultural resource that, for certain applications, can be used effectively in place of petroleum-based media.

Although wheat starch is relatively soft, it can be recycled several times before the particles become too small to be effective. As the media breaks down, dust-like particles must be stripped from coarser particles in the recycling process.

Wheat starch blasting is of interest primarily for its gentle stripping action. Thus, application and testing of this method have been focused on sensitive substrates, such as thin aluminum (e.g., in the aircraft industry) and fiberglass and certain plastics (e.g., in the automotive industry).

Key advantages of the wheat starch blasting approach include:

- *Sensitivity* Avoids damaging substrates; recommended particularly for substrates such as aluminum, soft alloys, anodized surfaces, and composites.
- *Selectivity.* Individual coatings can be removed (e.g., only the topcoat).
- *Minimizes pollution generation.* Avoids generation of VOCs and excess wastewater.
- *Recyclability* If the correct plastic media is selected, they can be recycled up to 30 times.
- *Moderate throughput.* Can be effective at a moderate coating removal rate.
- *Low-cost, biodegradable media.* Wheat starch is an inexpensive, renewable resource; spent media can be biodegraded from sludge.

Principal limitations of the wheat starch blasting approach include:

- Stripping action can be slow, depending on coating hardness.
- Media are sensitive to moisture and can require the addition of an air drying system in humid environments.
- Removal of the media dust and paint chips requires a somewhat extensive media recovery system.
- Dust generation can present an explosion potential unless precautions are taken.
- May not be appropriate for workpieces that are assemblies because media particles can become entrapped.
- Less effective than other methods for cleaning process equipment because of the heavy buildup of coatings.
- Less effective than other methods for removing rust and corrosion from metals.
- Contaminants remaining in the recycled media can damage substrates.

14.4.1.3 High- and Medium-Pressure Water Blasting

Water blasting is a well-established impaction method for high-throughput surface cleaning that has emerging applications for coating removal processes. This blasting approach involves subjecting workpieces to jets of water delivered at sufficient pressure from rotating nozzles to strip surface material without the benefit of an abrasive media. For high-pressure blasting operations, water is pumped at a rate ranging from 15,000 to 30,000 psi. Medium-pressure blasting is performed with water jets operating in the range of 3,000 to 15,000 psi.

This blasting approach generally avoids the generation of VOCs and other air quality issues associated with some wet blasting media. For some operations, however, workpieces first undergo a presoak with alcohol or a similar inorganic solvent. Water used in blasting operations can be recycled after if has been processed to remove debris.

In the automotive industry, medium-pressure water blasting is used for stripping overspray coatings from part support hooks used in water wall spray paint booths. Also, a German airline has used this approach with presoaking to strip aged coatings from planes. High-pressure water blasting is being developed by the U.S. Air Force for paint stripping operations on large aircraft. (Ultra high-pressure water blasting-from 30,000 to 50,000 psi-reportedly has been used selectively to remove resistant coatings in the automotive, aircraft, ship building, and nuclear industries [2].)

Key advantages of the water blasting approach include:

- *High throughput.* Can yield a high rate of coating removal.
- *Minimizes pollution generation.* Avoids generation of VOCs, dust, and spent media; wastewater can be treated in a conventional treatment system.
- *Recyclability* Water can be recycled after filtering out debris.
- Low *cost.* Medium-pressure operations can have low capital and operating costs.
- *Broad size applicability. No* workpiece size restrictions unless blasting cabinets are used; the process

can be used indoors or outdoors and in mobile operations.

Principal limitations of the water blasting approach include:

- Capital costs can be high if sophisticated systems are used (i.e., high-pressure systems would typically involve the use of robots).
- High volumes of water are necessary.
- A filtration system is required to recycle blasting water.
- Pressurized water jets can present a hazard to workers.

14.4.2 Abrasion Method

14.4.2.1 Sodium Bicarbonate Wet Blasting

Sodium bicarbonate wet blasting is an abrasion method that is similar in many respects to wheat starch blasting. The principal distinction is that the especially fine media used for this method (baking soda) scours the surface, rather than breaking up the coating by impaction. As with wheat starch blasting, this method is sufficiently gentle to remove coatings without damaging the substrate.

The media is delivered to the workpiece from a nozzle generally at low pressure with a wet blast system (i.e., in water at from 20 to 70 psi, although the system can deliver the media at up to 500 psi). As with other wet blasting approaches, the use of water avoids possible damage to the substrate from heat buildup and helps control dust generated by shattering of the media. Typically, a water rinse step follows the blasting step. Although the media cannot be recycled, they can be dissolved, leaving the coating debris to be filtered out for disposal.

Coatings can be removed by this method using modified sandblasting equipment. If the process is operated indoors, an exhaust ventilation system with a cyclone separator and intake piping must be added to control blast media overspray.

Sodium bicarbonate wet blasting has been used to remove both friable and elastomer organic coatings on sensitive workpieces, such as thin metal parts and machinery. This method is effective on both metal, plastics, and wood.

Key advantages of the sodium bicarbonate wet blasting approach include:

- Sensitivity. Avoids damaging substrates; recommended particularly for thin metals (e.g., aluminum, anodized aircraft skins), plastics and composites, and wood: in particular, heat sensitive substrates can be stripped because the blast water keeps the surface cool.
- Selectivity. Individual coatings can be removed (e.g., only the topcoat).
- *Minimizes pollution generation.* Avoids generation of VOCs and excess wastewater.
- *Process efficiency* Because the media are not recycled, the workpiece does not need to be cleaned prior to blasting.
- *Moderate throughput.* Can be effective at a moderate coating removal rate.
- *Low-cost media.* Sodium bicarbonate is inexpensive; spent media can be dissolved from sludge.

Principal limitations of the sodium bicarbonate wet blasting approach include:

- The media cannot be recycled.
- Operator safety measures and equipment must be included in the process (e.g., an exhaust ventilation system).
- Uninhibited sodium bicarbonate and water residue can corrode substrate.
- May not be appropriate for areas where water is in short supply.

14.4.3 Thermal Methods

14.4.3.1 Burnoff

Burnoff is a thermal method that involves a combination of volatilization, pyrolysis, and oxidation. This method of paint stripping is both fast and especially effective for resistant or accumulated coatings. Coating burnoff can be achieved using one of three methods, each of which requires subjecting workpieces to extremely high temperatures.

In direct burnoff, workpieces are passed through an oven in which high-temperature flue gas (1,000” to 1,200^{o}F) ignites the coating. Workpieces then might be subjected to an afterburner step before undergoing a step for removing inorganic residues. Another burnoff approach involves direct heating in an abrasive fluidized bed, where the coating is thermally degraded through pyrolysis and partial oxidation at a temperature of 900^{o} to 950°F. This approach requires the use of an afterburner to oxidize the intermediate organic products. The third approach relies on pyrolysis to volatilize the coating. The organic fumes generated by this process are treated in an afterburner, which converts hydrocarbons to carbon dioxide and water. Workpieces must then undergo a step for removal of inorganic residues. In the burnoff coating removal process, afterburners are generally capable of minimizing the generation of VOCs.

Other than monitoring, operation of a burnoff coating removal line involves mechanical or manual loading of workpieces. Systems are typically automated, however.

Burnoff is widely used to strip thick overspray buildup from a variety of process equipment used in paints and coatings operations. Burnoff technology may be useful for removing coatings from workpieces in certain operations, but limitations apply. For example, metals with a melting point below 900-F generally are not appropriate for this approach.

Key advantages of the burnoff approach include:

- *Performance.* Effective for rapid removal of heavy, resistant coating deposits.
- *Minimizes pollution generation.* Avoids generation of VOCs and excess wastewater.
- *Applicable for a wide range of part* sizes. Applicable to all shapes; limitations relate only to the size of the burnoff unit.

Principal limitations of the burnoff approach include:

- Temperatures are too high for parts made of plastics, composites, or metals -with relatively low melting points (e.g., zinc-bearing materials).
- Coatings that contain chlorinated compounds can emit hydrochloric acid; when part surfaces cool, hydrochloric acid together with atmospheric moisture can cause severe corrosion.
- Products of incomplete combustion containing heavy metals or other compounds may be generated, requiring disposal as a hazardous waste.
- Resulting gases can present risk of fire.
- Abatement equipment (e.g., scrubbers or filters) may be required for offgas treatment.

14.4.3.2 Molten Salt Bath Stripping

Molten salt bath stripping is a process that, like burnoff, is currently used primarily for fast removal of heavy coating deposits from process equipment used in paints and coatings operations. The molten salt process involves immersing parts (either in baskets or suspended from hooks) into a heated bath (from 550° to 900°F) containing inorganic salts (e.g., sodium carbonate). The salt functions as a heat transfer medium, subjecting immersed parts to uniformly high temperatures that result in chemical oxidation of the coating. Carbon and hydrogen in the coating are oxidized to carbon dioxide and water. The exothermic reaction that occurs in the molten salt bath minimizes the loss of heat that might otherwise result from the immersion of cool parts. In general, metals from the coating pigments are retained in the molten salt bath, entering the offgas only in small amounts.

After the reaction has ceased, parts are removed from the bath and allowed to cool. A thin coating of salt will have formed on part surfaces and must be removed. This is accomplished by rinsing the parts in a tap water bath at ambient temperature.

Along with sludge containing primarily metal salts, the process generates offgases and wastewater from the rinsing step. Thus, operators must make provisions for sludge disposal and include offgas abatement equipment and wastewater treatment in their process line.

Molten salt bath stripping is used primarily for supports and fixtures used in coating application lines. The approach is relatively fast (bath dwell times range from seconds to minutes) and particularly effective on heavy, resistant coatings. It can be used to remove a variety of organic coatings, including nylon, polyester, and epoxies.

Key advantages of the burnoff approach include:

- *Performance.* Effective for rapid removal of heavy, resistant coating deposits.
- *Pollution prevention. No* VOCs (or odors) are generated.
- *Applicable for a wide range of part* sizes. Applicable to all shapes; limitations relate only to the size of the bath.
- Not *time-critical.* If the metal substrate can withstand immersion in the molten bath, the substrate will not be harmed by overexposure (e.g., applies to most steels and to aluminum).
- *Long bath life.* Sludge must be removed, but the bath itself does not need to be dumped and replenished.
- *Minimal treatment required for waste rinse water.* After making minor pH adjustments with a mineral acid, rinse water can be discharged; alternatively, because of its high pH, the water can be used beneficially to neutralize wastewater from other acidic operations (e.g., from an acid pickling or phosphating process).

Principal limitations of the molten salt bath approach include:

- Generated sludge must be disposed of and rinse wastewater treated.
- Abatement equipment (e.g., scrubbers or filters) is required for offgas treatment.
- Temperatures are too high for parts made of plastics, composites, or metals with relatively low melting points (e.g., some die-cast alloys).
- Not appropriate for parts with sealed tubing because internal pressure buildup can cause tube or weld failures and pose a threat of explosion.
- Operator safety measures and equipment must be included in the process (e.g., a fume hood must be installed to remove smoke generated by the process).

14.4.4 Cryogenic Methods

14.4.4.1 Carbon Dioxide Pellet Blasting

Carbon dioxide (CO,) pellet blasting is a cryogenic method capable of removing coatings from specified areas of a workpiece while minimizing the amount of residue left on the piece's surface. The approach involves projecting dry ice pellets at a workpiece's surface (at from 75 to 1,000 ft/sec) from a nozzle. (A centrifugal projection system is in development.)

The equipment for this technology includes a system for converting refrigerated liquid CO_2 into the pelletized blasting media. The media remove coatings by a combination of impact, embrittlement, thermal contraction, and gas expansion. After the pellets strike the workpiece surface, they revert to a gaseous state, both enhancing coating removal and avoiding significant residue buildup. After blasting, workpieces are subjected to jets of air to remove coating fragments.

Because the approach can strip coatings selectively (i.e., specific areas of a workpiece as well as individual coating layers), it has broad application for industries processing sophisticated parts and components. Applications include the aerospace, automotive, electronics, and food processing industries. For example, this method can be used on surfaces near moving parts and on sensitive electronic pieces.

Key advantages of the CO_2 pellet cryogenic blasting approach include:

- *Selectivity/sensitivity.* Can be used on specific areas of a workpiece and to remove individual coatings.
- *Process efficiency* Minimizes residue on workpiece surfaces. Also, the need for masking is either eliminated or reduced to a minimum.
- *Pollution prevention.* Generates only small amounts of solid waste; also avoids handling of spent media and wastewater.
- *Broad applicability* Can be used on a variety of substrates (e.g., steel, aluminum, printed circuit boards, fiberglass, plastics).
- *Minimized hazards.* Uses a nonflammable, nonconductive blast media.

Principal limitations of the CO_2 pellet cryogenic blasting approach include:

- Media cannot be recycled.
- Process equipment is relatively expensive.
- Throughput can be slow for workpieces with resistant coatings.
- Condensation can occur on the workpiece surface.
- Safety equipment must be included in the process (e.g., a ventilation system for CO_2 gas).

14.4.4.2 Liquid Nitrogen Blasting

Liquid nitrogen cryogenic blasting is a variation of the PMB method that involves chilling the workpiece to embrittle the coating before subjecting it to impaction with a plastic media. The piece is sprayed with liquid nitrogen as it rotates on a spindle within a cabinet, and then is blasted with the impaction media, which are projected into the cabinet by throw wheels.

After chilling the coating (to about -32O^{o}F), the liquid nitrogen warms to ambient temperatures and evaporates into a gaseous form. This harmless gas can be vented to the atmosphere, leaving the media to be collected, separated from coating debris, and recycled.

The liquid nitrogen cryogenic blasting approach is used primarily to remove coating buildup from certain types of process equipment used in paints and coatings operations (e.g., paint hangers, coating racks, floor gratings). Operations in the automotive and appliance industries have used this method with success.

Key advantages of the liquid nitrogen cryogenic blasting approach include:

- *Minimizes pollution generation.* Avoids generation of wastewater and VOCs; because the process is dry, no water is used.
- *Recyclability* If the correct plastic media is selected, they can be recycled numerous times.
- *High throughput.* Can be effective at a relatively high coating removal rate.
- *Low operating costs.* Compressed air and electricity requirements are low.

Principal limitations of the liquid nitrogen cryogenic blasting approach include:

- Capital and startup costs can be high.
- Not appropriate for thin coatings and less effective on epoxies and urethanes.
- The stripping cabinet restricts the size of parts that can be processed.

14.5 References

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2. U.S. Environmental Protection Agency. 1991. Reducing Risk in Paint Stripping: Proceeding of an International Conference. Washington, DC, February 12-13. NTIS PB91-224-303. Office of Toxic Substances, Washington, DC.

Chapter 15
Minimizing Pollution in Spray Booths

15.1 Introduction

15.1.1 Pollution Prevention Considerations

Almost every paint facility that applies coatings by spray has at least one spray booth on the premises. This chapter describes the most common booths. By manipulating inefficient spray booth parameters, facilities can minimize rejects and reworks, thus lowering all forms of pollution.

Efficient operation of nearly all spray booths requires that they capture and retain paint particulates using either dry filters or water. Thereafter, facilities must dispose of the medium (filters or water) together with the overspray. In large facilities, disposal can be a major problem because waste is so voluminous. Moreover, disposing of these large quantities can be costly.

Unfortunately, most companies purchase their dry filters on the basis of price rather than efficiency and holding capacity. This chapter offers guidelines for selecting the most appropriate filters. Alternately, water-wash spray booths require chemicals to detackify or “kill” the paint overspray. Because selecting the most appropriate chemical(s) is more complex than simply choosing a highly alkaline hydroxide, the chapter also offers advice for making this choice properly.

Beyond these most basic decisions, recognizing and altering the other factors that contribute to rejects and reworks allows facilities to minimize pollution and maximize efficiency. Transfer efficiency of a spray application is very sensitive to booth conditions, particularly air flow. Moreover, many coating defects result from poor booth design, poor booth maintenance, improper air flow, high booth humidity, and other factors. Rework of large machines can require major repaints, which result in the unnecessary use of coatings. This of course leads to more air, water, and waste pollution, as well as higher overall finishing costs.

The primary purpose of this chapter is to provide a background concerning spray booths, and to outline strategies for minimizing reworks that result from spray booth parameters. As most previous chapters have explained, a reduction in rework automatically lowers all forms of pollution and improves the bottom line.

15.1.2 Decision-Making Criteria

Decision-making criteria relevant to minimizing pollution in spray booths, as addressed in this chapter, are highlighted in Table 15-1.

15.2 Definition and Function of Spray Booths

A spray booth is an enclosure that directs overspray and solvent emissions from painting operations away from the paint operator and toward an entrainment section. Note that a spray booth is an abatement device for particulates It is not an abatement device for volatile organic compounds (VOCs). One can assume that all conventional spray booths emit all of the coatings’ VOCs through the stack of the booth or from the booth openings. The spray booth primarily exists to protect the spray painters and other employees from exposure to potentially toxic vapors and particulates.

High concentrations of flammable solvent vapors always constitute a fire hazard, particularly in facilities with welding and other spark-producing operations. Thus, another function of the spray booth is to prevent fires within a facility. Without spray booths, the risk of collecting a high concentration of flammable vapors in a facility is high. Booths quickly and efficiently exhaust the vapors to the atmosphere where the outside air dilutes them so they no longer cause concern for a fire.

Some researchers have tried to determine whether VOC emissions can be concentrated by recycling the VOC-laden air back to the booth and then bleeding only a portion of it off to the outside. One of the industry’s primary concerns is that this process can expose spray painters to high concentrations of VOCs, although this can be mitigated by providing the painters with fully air conditioned suits so that they breath only outside clean air. In fact, experimental work is now taking place at a Marine Corps base in Barstow, California, to further explore this concept. Ayer (1) has already shown that recycling the air and bleeding off only a small fraction, which a thermal oxidizer or carbon adsorber will then abate, is both cost-effective and environmentally sound.

Table 15-1. Decision-Making Criteria Regarding Minimizing Pollution in Spray Booths

Issue	Considerations
Are the workpieces generally small and are they suspended from a conveyor or rack, or are they on pallets?	· If yes and if the paint operator will always stand facing the filtering area, then using a cross-draft booth is probably best. · If yes but the paint operator must walk around the workpieces in order to spray from all sides, consider redesigning the conveyor or rack to one that rotates the workpieces, allowing the paint operator to always face the filtering area; then a cross-draft booth would work. · If no, or if redesign of the conveyor or rack is not an option, you may need to consider a down or semi-down draft booth, even though it may cost more than a cross-draft booth.
Are the workpieces large and long, such as trucks, and must the paint operator paint predominantly from the sides?	· If yes, consider using a cross-draft booth, but ensure that air flows parallel to the floor toward the filters.
Are the workpieces large and long and must the paint operator paint from the sides, the top, and possibly the bottom?	· If yes, consider a down or semi-down draft booth.
Can defects in the paint, such as settling of dust, be tolerated (e.g., paint operator is applying a primer, or a primer/topcoat system for workpieces that do not have high visibility)?	· If yes, consider a two- or three-sided open booth. · If yes, but overspray from the operation would enter the factory work area, affecting other workers and depositing on machinery, consider a totally enclosed spray booth. · If no because the coating must be free of dust and dirt, consider using a totally enclosed booth that draws air from either the factory area or, for even cleaner finishes, from clean outside air via an air make-up unit.
Is the facility located in a cold or hot climate where spray booth air can go below 50°F or above 8O°F, and must the coated finish be consistent, and have a high quality appearance?	· If yes, consider installing temperature controls as part of an air-make-up system.
Is the facility located in a humid climate where the air in the spray booth can reach a relative humidity in the 90 percent range?	· If yes and if the paint operators are applying water-borne coatings, polyurethanes, moisture-sensitive coatings, or fast-evaporating solvent-borne paints, then consider dehumidifying the incoming air, preferably to 50 to 55 percent, although such low humidity levels might prove cost-prohibitive.
Is coating usage generally less than 2 gallons/day per square foot of filtering surface area?	· If yes, you should probably use a dry filter spray booth. · Even if coating usage is considerably higher, calculate the cost-effectiveness of using a dry filter versus water-wash booth since water-wash booths are associated with so many costs (i.e., dry filter booths require disposal of spent filters whereas water-wash booths require disposal of wet paint sludge as hazardous waste, buying necessary chemicals, occasional disposal of water in trough, etc.).
Is coating usage higher than 2 gallons/day per square foot of filtering surface area?	· If yes, you may need to consider a water-wash booth but must first calculate its cost-effectiveness versus a dry filter booth.
Is the facility operator currently using inexpensive paper or cardboard filters and finding the cost to **dispose** of these filters to be a major problem?	· If yes, consider using a filter medium with a higher holding capacity. Although filter cost would be higher, cost savings from lower disposal costs would be significant; therefore, perform a cost-effectiveness analysis, consulting vendors for the wide range of available media. · If considering switching to expanded polystyrene filters, experiment with them first to evaluate their cost-effectiveness. Brushing off dry overspray allows re-use of these filters but disposal may involve dissolving them in solvent waste and disposing of them as liquid hazardous waste.
Is the facility operator currently using water-wash spray booths and finding the disposal of wet sludge to be a problem?	· If yes, consider reviewing the chemicals currently in use because generally, chemicals are available that detackify the sludge, allowing for disposal of relatively dry sludge. A cost-analysis can determine if the resulting reduction in hazardous waste disposal costs justifies using the newer, more expensive chemicals.

15.3 Spray Booth Design

Spray booths come in all types of styles and configurations:

- Large or small
- Open or enclosed
- Bench type, walk-in, or drive-through
- Cross-draft, down draft, or semi-down draft
- Dry filter, water-wash, or baffle

The rest of the chapter provides guidelines for determining what type of booth is probably the most appropriate for a particular application.

Facilities select the size of the booth based on the size of the largest workpieces they must coat. If very few large workpieces need coating in relation to the number of smaller parts, it may be more economical to install two booths: an inexpensive booth for the large pieces, and a more sophisticated booth for the remainder of the work.

Although a spray booth is generally thought of as an enclosure, the booth need not be totally enclosed. For instance, when painting very large workpieces, an operator's booth may comprise only one side, namely the exhaust plenum that draws the solvents and particulates away from the operator (see Figure 15-1a).

It is also not uncommon to install two spray booths opposite one another (see Figure 15-1b). This set-up allows very large workpieces to be transported in between the two booths, either via a conveyor that runs between the booths or a forklift truck. Often neither booth has a ceiling, and they draw air from the surrounding factory itself.

Spray booths can also be small enough to fit onto a laboratory bench. It is not unusual to see a spray booth that is 5 feet wide and only 4 or 5 feet high.

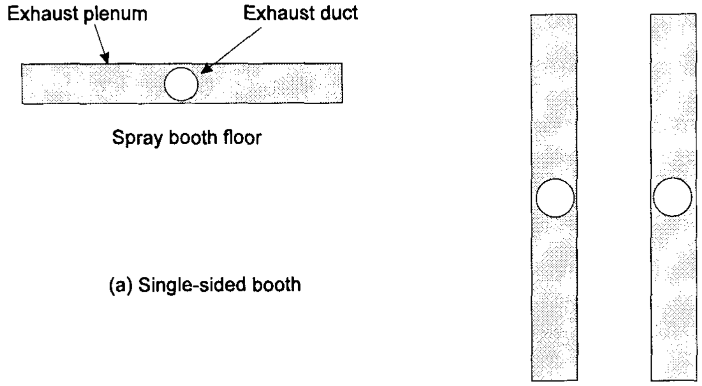
Spray booths with three sides have the exhaust plenum along with two additional sides which simply prevent the solvents and overspray from migrating into other parts of the operations facility. Moreover, these sides promote more efficient air flow through the booth (see Figure 15-1c).

Totally enclosed booths comprise one or two sides with the exhaust plenum(s). One of the other sides usually contains the doors that can be opened to allow operators to drive the workpieces into the booth (see Figure 15-1d).

15.3.1 Cross-Draft

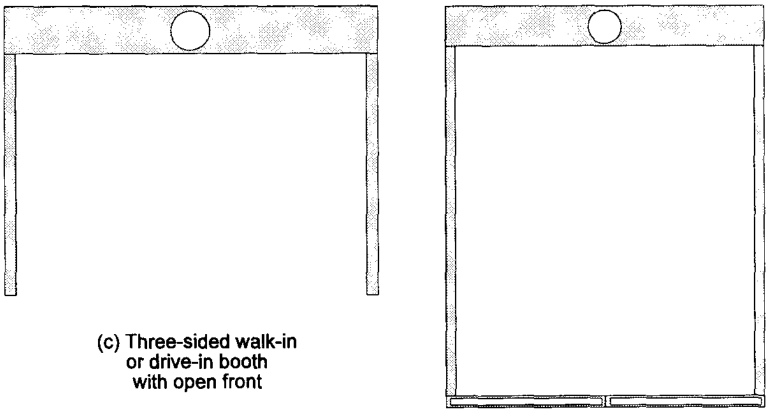
In a cross-draft spray booth the air moves from behind the operator toward the dry filter or water curtain (see Figure 15-2). The air travels parallel to the floor.

This type of booth is ideal when parts are suspended from racks or a conveyor, and the spray painter applies the coating essentially from only one direction. If, however, both sides of the part require coating, two options are available:



(a) Single-sided booth

(b) Two booths facing each other (2-Sided)



(c) Three-sided walk-in or drive-in booth with open front

(d) Totally enclosed drive-in booth with doors in front

Figure **15-1. Spray booth design concepts.**

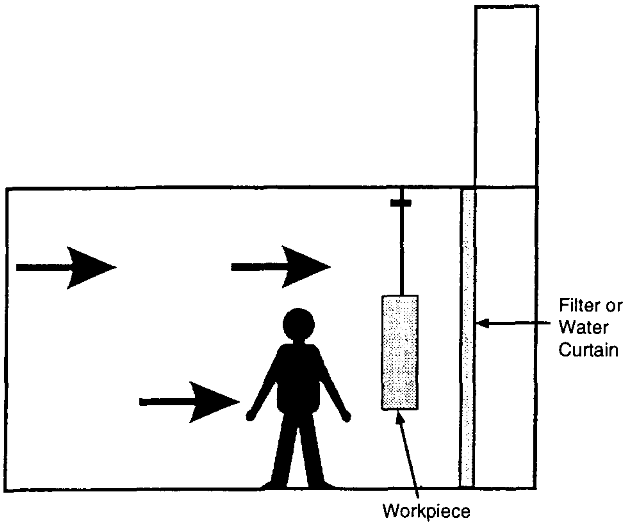


Figure **15-2. Cross-draft spray booth.**

- The spray painter can rotate the part manually or, if a conveyor is used, it can contain a spindle that automatically rotates the part.
- The facility operator can install a second cross-draft booth that sits side-by-side with the first (see Figure 15-3).

Facilities that do not require high-quality coating finishes can draw the incoming air from the factory space around the booth. Facilities in cold climates or those that require high-quality, defect-free finishes can install an air make-up unit on the roof of either the booth or the factory building, and draw clean outside air into the booth.

Cross-draft booths are usually less expensive than down draft or semi-down draft booths. Vendors can provide detailed cost comparisons based on customer requirements.

15.3.2 Down Draft

Down draft spray booths move the air from the ceiling of the booth vertically downward toward the exhaust plenum in the floor.

These types of booths have several strengths:

- They remove the particulates by blowing the polluted air downward from the painter's face, minimizing the potential for inhalation.
- When coating a large machine, they pull the overspray in the shortest direction, downward, thus preventing overspray from collecting on the freshly painted sides of the machine.
- They allow more than one spray painter to coat the workpiece at the same time; overspray does not blow from one operator toward the face of another (see Figure 15-4).
- They have the potential to provide the highest quality finishes.

The down draft booth is preferred when the paint operator walks around the part. This method is particularly popular when painting large machines or vehicles (which cannot be rotated) that sit on a floor or grating. In fact, most facilities that paint large workpieces such as weldments, assembled machines, vehicles, etc., use a down draft spray booth.

These booths usually cost more than the cross-draft booths because they require a pit below the floor of the booth. The facility operator can either have the pit dug from the floor of the factory or elevate the booth so that the pit sits on the floor. In the latter design, three or four steps lead from the floor into the booth. The advantage of the first design is that operators can drive large workpieces into the booth, either on their own power or by a forklift truck. The primary disadvantage is that the pit must be dug below the factory floor. The advantage of the elevated booth is that it is less expensive, but this is offset by the inability to drive workpieces into the booth. Instead, either a conveyor or a hoist crane is necessary to perform this function.

Some down draft spray booths do not have a ceiling, and draw incoming air from the surrounding factory area. Most booths have a ceiling, however, and draw air either from the factory area or from the outside. The

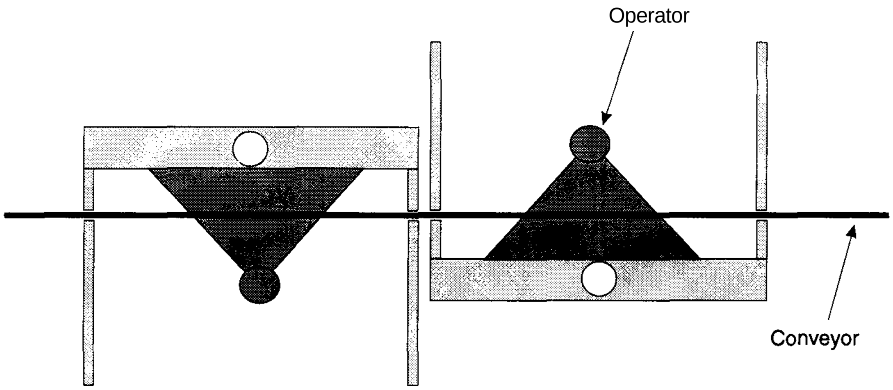


Figure 15-3. Side-by-side cross-draft booths.

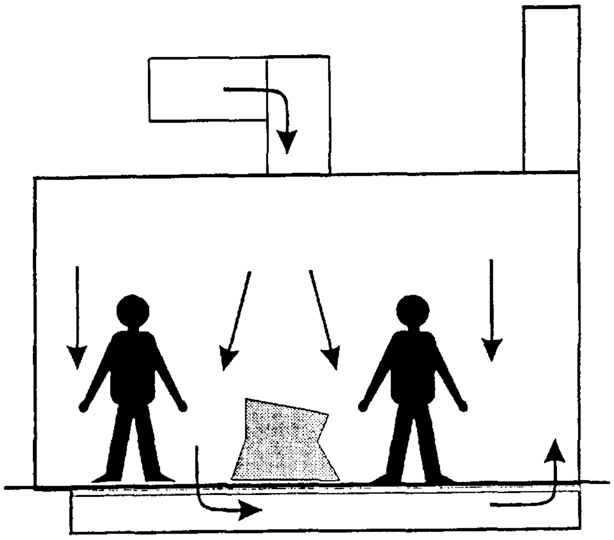


Figure 15-4. Down draft spray booth.

need for a heated or unheated air make-up unit depends on climatic conditions and the need for a high quality, defect-free finish. For instance, it is always advantageous to maintain the booth temperature at between 65° and 80°F, but very few companies feel they can afford the cost of controlling the temperature of high volume air flow rates. Facilities that produce high-quality finishes and are located in very cold climates (in winter) and/or very hot climates (in summer), however, often have little choice but to provide temperature controls.

Similarly, it is usually beneficial to control the relative humidity in the booth at less than 50 percent, particularly when using water-borne coatings, polyurethanes, and other moisture-sensitive resins. This is because humidity can affect the drying time of water-borne coatings, while it can cause blemishes in polyurethane coatings. The costs associated with controlling humidity can be prohibitive. Despite these high costs, companies that must produce high-quality finishes free from defects do indeed need to invest in air conditioning controls.

While the capital cost of a down draft booth usually exceeds that of a cross-draft booth, the operating expense is almost always considerably higher, primarily because of higher air flow requirements.

For example, Occupational Safety and Health Administration (OSHA) requires that the minimum air velocity through a spray booth exceeds 100 feet per minute (fpm) in the direction of the exhaust plenum or filter bank, and primarily away from the face of the operator. The following equation expresses the volumetric air flow:

Volumetric flow (cfm) = Velocity (fpm) x Cross-sectional area (square feet) of the filter opening

Consider two spray booths, each of identical interior dimensions. If the booth is 10 feet high x 8 feet wide x 15 feet deep, then for a cross-draft booth the minimum air flow would be:

8,000 cfm = 100 (fpm) x 10 feet x 8 feet

If the booth is a down draft design, and the entire floor opening draws air, then the minimum air flow would be:

12,000 cfm = 100 (fpm) x 8 feet x 15 feet

In most cases, a down draft booth draws more air than a cross-draft booth, and the energy requirements increase proportionally. If the booth requires heat to warm the air during the winter months, the energy requirements are accentuated.

In addition, because the floor opening is usually significantly larger for a down draft booth than for a cross-draft design, the cost of replacing and disposing of spent dry filters, water, and chemicals are considerably higher.

These are all factors a facility operator must consider before selecting a down draft booth.

15.3.3 Semi-down Draft

Semi-down draft booths offer two different designs. First, the booth can move the air from the ceiling at the front of the booth toward the floor at the back of the booth where the exhaust is located. Air movement is in a diagonal direction. Alternatively, the air can move from the center of the ceiling down toward one of two level exhaust plenums located along the side walls of the booth. Figure 15-5 illustrates these two types of semi-down draft designs.

Semi-down draft booths offer a compromise between the cross-draft and down draft configurations and provide many of the advantages of the other designs.

Companies choose between cross, down, and semi-down draft booths based on the type of workpieces they must paint. When paint operators must walk around a large workpiece, the choice is usually between a down or semi-down draft booth. The latter is less expensive because it does not require a pit below the floor for the exhaust plenum.

15.4 Dry Filter Spray Booths

Because the choice between dry filter, water-wash, and baffle spray booths encompasses many issues, separate sections discuss each of these types of booths.

Vickers (2) estimates that 80 percent or more of spray booths used in paint facilities are of the dry filter type. In recent years, many facilities have converted water-wash booths to dry filter because of their lower maintenance costs and the often significantly lower hazardous waste costs. The cost to actually purchase dry filters ranges

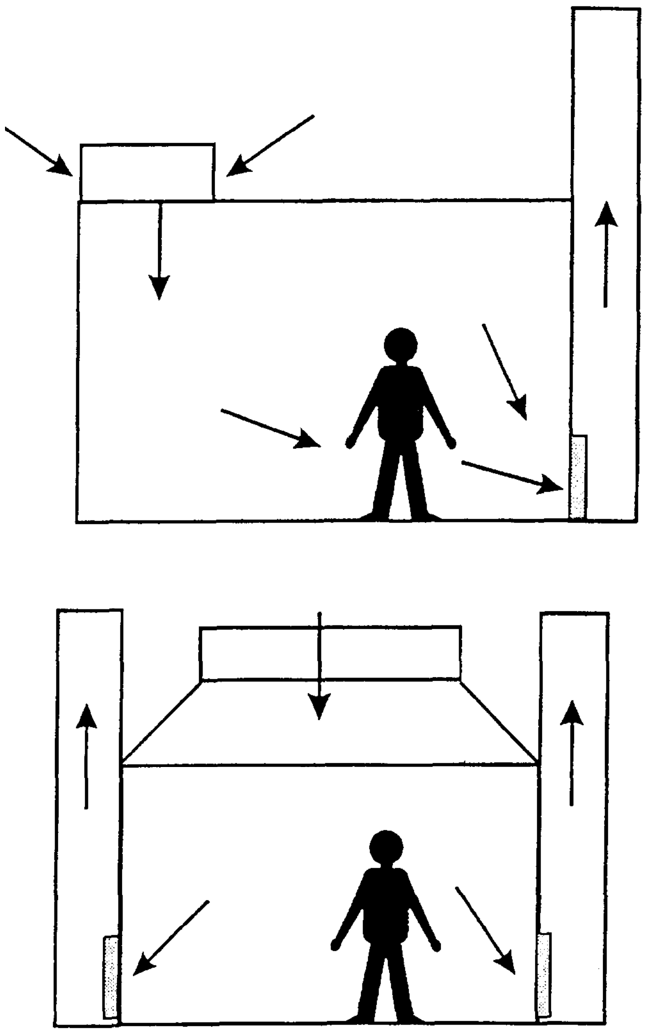


Figure 15-5. Semi-down draft spray booths.

from $1 to $5 per filter, depending on a filter's efficiency, holding capacity, and other characteristics.

15.4.1 Advantages

The advantages of dry filter spray booths are plentiful and varied, ranging in areas from effectiveness to pollution prevention. For instance, regarding effectiveness, dry filters effectively remove up to 95 to 99 percent of particulates. High efficiency filters can reliably retain 99 percent of particulates. As a rule-of-thumb they are ideal for low paint loading, i.e., approximately 2 to 5 gallon coating usage per square foot of filter area per day.

They are also quite versatile. Facilities can use dry filters in booths of all designs (small, large, cross-draft, down draft, and semi-down draft). In addition, a wide selection of available dry filter media can satisfy many end-users. Filters can accommodate companies that require the highest paint finish quality without constraints on the cost of the filters, as well as those having very low appearance requirements and wishing to purchase the least expensive.

Unlike water-wash spray booths, facilities can operate dry filter booths even when using a range of coating technologies (e.g., polyurethanes, epoxies, alkyds, etc.) on the same day. Some exceptions, however, do exist:

- If using nitrocellulose paints, auto-ignition (fire) is possible if non-compatible coating is also deposited onto some filters. Thus, do not apply nitrocellulose coatings and those of other resin technologies in the same booth.
- Some filters are not suitable for water-borne coatings. Thus, if using solvent-borne and water-borne coatings in the same booth, select filters that are compatible with both.

Finally, dry filter booths are relatively inexpensive when compared with water-wash booths. This is partially because of low maintenance and partially because of low waste disposal requirements. Maintenance essentially only requires periodic replacement of the filter media. The cost of waste disposal can be negligible. Some companies dispose of their dry filters as follows:

- They leave filters in the open to allow all solvents to flash off.
- If using baking enamels, they place filters in a baking oven to allow the paint overspray to fully cure.
- They conduct a toxicity characteristic leaching procedure (TCLP) test (usually only the first time this procedure is carried out) to confirm that the filters do pass the test (i.e., that they are not hazardous). If the filters pass the test, they are disposed of in a dumpster. If they fail the tests (i.e., if they are hazardous), they are sent out as solid hazardous waste.

This TCLP test strategy alone can dramatically lower the generation of hazardous waste. At best, the filters do not constitute waste at all, and at worst, companies dispose of them as solid hazardous waste, for which the disposal costs are considerably less than for liquid hazardous waste. If, however, a company would like to follow the testing guidelines outlined above, it must take the following precautions:

- Ensure that the state acknowledges that dry filters containing cured paint that have passed the TCLP test can legally be disposed of as garbage.
- Ensure that the spent filters are tested for TCLP.
- If the contaminated filters pass the TCLP test, but at some time in the future the coatings change, then the TCLP test must be conducted again to confirm that the new coatings also pass the test.
- The precaution to recheck for TCLP applies also if the new coating is a low-VOC water-borne. Do not assume that water-borne coatings are non-hazardous. Some

contain heavy metals and other ingredients that would cause the filters to fail the test.

15.4.2 Disadvantages

While dry filters are ideal for some paint facilities, they do have limitations. For instance, they are generally not appropriate for large coating usage, i.e., greater than 5 gallons per square foot of filter area per day. They also have disadvantages that affect their pollution and safety profiles, as well as their cost.

Unless using continuous roll-up filters, which are prohibitively expensive for most companies, air flow through the booth diminishes as the filters load up with overspray. This can be a major drawback if air flow plays an important role in the finishing operation. (See Case Study #3 in Chapter 16.) In some facilities, an enclosed finishing room comprises several spray booths. In most cases, the booths do not each have an air make-up unit, but all draw air from only one inlet duct. As each dry filter section becomes loaded with overspray, the air flow within the finishing room constantly changes, causing quality problems. Turning the blowers on and off during the working shift aggravates the situation. In extreme cases, the air flow can become so turbulent that it continuously changes direction (e.g., moving toward the filter bank for a few seconds, and then reversing itself for the next few seconds). Such turbulent air can carry overspray from one booth onto freshly painted surfaces in the other booth(s). This cross-contamination can lead to very expensive reworks and rejects, and ultimately results in unnecessary pollution and costs. Another pollution-related consideration is that dry filters do not remove VOCs.

Regarding safety, dry filters are a potential fire hazard, particularly if dry overspray is allowed to build up. Overspray of coatings, such as nitrocellulose lacquers, can cause spontaneous combustion. Fortunately, nitrocellulose coatings are phasing out and states that enforce low VOC limits on coatings have all but outlawed them. Because of their risk of fire, installation of a sprinkler system is a requirement.

Finally, storage of unused filters requires space. Facilities with large spray booths may find this problematic. In addition, used, spent filters are bulky and also occupy much space. This potentially increases the cost of disposal.

15.4.3 Selecting Dry Filter Media

When selecting the proper dry filter, facilities need to take into account several filter characteristics. Among these are:

- Efficiency
- Resistance
- Holding capacity
- Incineration profile
- Biodegradability
- Landfill option profile
- Flammability
- Suitability for various coatings

Efficiency is the ability of the filter to remove particulates before they can enter the exhaust stack. Selecting a filter that has a high retention efficiency, at least 96 to 99 percent, is important. Note, however, that the efficiency only affects the amount of particulates, or PM_{lo}, that escapes into the air. Some state regulations place daily limits on the amount of PM_{lo} that facilities can emit, and here the retention efficiency of the filters can be crucial to compliance.

If the efficiency is relatively low, less than 96 percent, escaping particulates can possibly settle outdoors, even on vehicles in the employee parking lot. Companies that have experienced these problems have found it well worth the expense to purchase higher efficiency filters. Also, note that the retention efficiency of the filters has no bearing on the amount of hazardous waste that may require disposal.

In addition, high efficiency filters reduce the loading of overspray on surfaces inside the spray booth exhaust duct, and particularly on the fan impeller. This, in turn, reduces the frequency with which the interior section of the booth requires cleaning. If a significant amount of overspray escapes into the spray booth stack, it can increase the energy required to drive the impeller. High efficiency filters minimize this problem.

Resistance of a filter refers to the pressure differential that ensues when the high velocity air passes across the filter bank. Facilities should select a filter with low air flow resistance. While this strategy lowers the energy costs required to run the booth, it is unlikely to have an impact on pollution.

Holding capacity is the amount of overspray that a filter can hold or retain during its service life. Selecting a filter medium with a high loading capacity is wise. This reduces the frequency for replacing the filters, and reduces the volume of waste that may require disposal as hazardous solid waste.

Facilities should check on whether they can incinerate the filters and that the filters meet all incinerator standards. This gives the end-user the option to incinerate the filters rather than to dispose of them as a solid hazardous or non-hazardous waste. The end-user should first determine whether incineration is an acceptable procedure within the state. Some states may not allow incineration by the end-user, although a certified waste incineration company may be able to perform this function.

Facilities also may find it advantageous to use filters that are biodegradable. Regardless of this, facilities should check to ensure that the filters meet all landfill standards.

Another important factor is flammability. Check that the filters meet the requirements of the National Fire Protection Bulletin #33 and that Underwriter's Laboratories has approved the filters as Class 2.

Finally, some water-borne coatings can complicate the choice of dry filter used. Some filters, particularly if made of paper, may not be suitable for water-borne coatings.

The literature contains very little concerning the selection of dry filters for capturing paint particulates. Vickers (2) provides some interesting information about the materials manufacturers use to make spray booth filters. Howery (3) has presented an excellent paper addressing the properties of different dry filter media (see Table 15-2).

Table 15-2 shows that when filtering high solids baking enamel, filters such as the standard filter have a low retention efficiency of 96.5 to 97.5 percent and a low holding capacity of only 2.8 pounds per filter pad. Compare this with the high efficiency filter that has a retention efficiency of 98.5 to 99 percent and a corresponding holding capacity of 5.4 pounds per filter pad. The standard filter is a low-cost paper or cardboard filter, while the high efficiency filter comprises several layers of material, including Kraft paper and several layers of fiberglass matting, each with progressively smaller porosities.

Tables 15-3 and 15-4 provide the worksheets for hypothetical paint facilities using 65 and 30 percent transfer efficiency as the basis. Both values seem reasonable for a typical paint facility. The 30 percent value represents the average small-to-medium parts facility, while the 65 percent value represents medium-to-large size parts and machines. This worksheet model allows one to

Table 15-2. Efficiency and Holding Capacity of Dry Filters[a] (3)

Description	Efficiency	Holding Capacity
	High Solids Baking Enamel Average Efficiency Range	Holding Capacity[b] (inches, water column)
Standard filter	96.5 - 97.5	2.8 lbs @ 0.10
High-capacity filter	94.0 - 96.0	6.5 lbs @ 0.10
High-efficiency filter	98.5 - 99.5	5.4 lbs @ 0.50
	Water-Borne Bake Enamel Average Efficiency Range	Holding Capacity[b] (inches, water column)
Standard filter	93.0 - 94.0	4.8 lbs @ 0.50
High-capacity filter	91.5 - 92.5	8.7 lbs @ 0.50
High-efficiency filter	97.0 - 98.0	4.0 **lbs @ 0.50**

[a] Performance figures were obtained using representative current industry coatings in an air-atomizing gun with two pads in tandem at a face velocity of 200 fpm.

[b] Test paint was very fluid and slow drying, resulting In excessive run-off on standard and high-capacity filters, with little resistance increase.

Table 15-3. Cost of Waste With 65 Percent Transfer Efficiency

Table of Assumptions (Vary Filter Holding Capacity and Cost of Filter)	
Surface area to be coated	3,500.00 ft^2/day
VOC of coating	3.5 lb/gal
Density of VOC portion	7.36 lb/gal
% Volume solids	52.45%
Weight per gal (WPG)	9.8 lb/gal
% Weight solids (Calculated)	64.29%
Cost of coating	$20.00 $/gal
Dry film thickness	1.5 mil
Transfer efficiency	65%
Size of filters	20" x 20"
Number of filters across	8
Number of filters down	4
Total number filters affected	32
Holding capacity of filters	3 lb/filter
Percent of overspray going into filters	60%
Percent efficiency of the filters	99%
Percentage PM_{lo} in the overspray	99%
Cost of filters	$1.OO/filter
Number of filters which can be disposed of in 55-gal drum	40 filters/drum
Cost to dispose of 55-gal drum	$300.00 $/drum
Days of operation	251 days/yr
Labor required to replace filters	0.5 hours
Labor rate	$15.00 $/hour
Calculations	
Total liquid gallons required	9.60 gal/day
Total liquid coating used	2,409.94 gal/yr
Total solid coating used	1,263.91 solid gal/yr
Density of solid coating (Calculated)	12.01 lb/gal
Weight of solid coating used	15,182.61 lb solid/yr
Weight of total solid overspray	5,313.91 lb solid/yr
Weight of solid overspray in filters	3,188.35 lb solidlyr
Number of filters to be disposed of	1,062.78 filters/yr
Number of filter changes per year	33.21 filter changes/yr
Number of 55.gallon drums to be disposed of	26.57 drums/yr
Cost of hazardous waste disposal	$7,970.87 $/yr
Cost of filters	$1,062.78 $/yr
Labor hours to change filters	16.61 hours/yr
Labor cost to change filters	$249.09 $/yr
Number of wasted gallons	843.48 gal/yr
Cost of wasted paint	$16,869.56 $/yr
Summary	
Cost of waste + filters + labor	$9,282.74 $/yr
Cost of wasted paint	$16,869.56 $/yr
Total cost of waste	$26,152.30 $/yr

Table 15-4. Cost of Waste With 30 Percent Transfer Efficiency

Table of Assumptions (Vary Filter Holding Capacity and Cost of Filter)	
Surface area to be coated	3,500.OO ft^2/day
VOC of coating	3.5 lb/gal
Density of VOC portion	7.36 lb/gal
% Volume solids	52.45%
Weight per gal (WPG)	9.8 lb/gal
% Weight solids (Calculated)	64.29%
Cost of coating	$20.00 $/gal
Dry film thickness	1.5 mil
Transfer efficiency	30%
Size of filters	20” x 20”
Number of filters across	8
Number of filters down	4
Total number filters affected	32
Holding capacity of filters	3 lb/filter
Percent of overspray going into filters	60%
Percent efficiency of the filters	99%
Percentage PM_{10} in the overspray	99%
Cost of filters	$1.00/filter
Number of filters which can be disposed of in 55-gal drum	40 filters/drum
Cost to dispose of 55-gal drum	$300.00 $/drum
Days of operation	251 days/yr
Labor required to replace filters	0.5 hours
Labor rate	$15.00 $/hour
Calculations	
Total liquid gallons required	20.80 gal/day
Total liquid coating used	5,221.53 gal/yr
Total solid coating used	2,738.47 solid gal/yr
Density of solid coating (Calculated)	12.01 lb/gal
Weight of solid coating used	32,895.65 lb solid/yr
Weight of total solid overspray	23,026.95 lb solid/yr
Weight of solid overspray in filters	13,816.17 lb solidfyr
Number of filters to be disposed of	4,605.39 filters/yr
Number of filter changes per year	143.92 filter change/yr
Number of 55-gallon drums to be disposed of	115.13 drums/yr
Cost of hazardous waste disposal	$34,540.43 $/yr
Cost of filters	$4,605.39 $/yr
Labor hours to change filters	71.96 hours/yr
Labor cost to change filters	$1,079.39 $/yr
Number of wasted gallons	3,655.07 gal/yr
Cost of wasted paint	$73,101.44 $/yr
Summary	
Cost of waste + filters + labor	$40.225.21 $/yr
Cost of wasted paint	$73,101.44 $/yr
Total cost of waste	$113,326.65 $/yr

calculate the total costs of hazardous waste from a dry filter spray booth. The first half of each of the tables provides the assumptions used, and the second half provides the calculated results.

Figure 15-6 charts the cost of filter disposal for different filters of increasing holding capacity. In producing the chart, the same two transfer efficiency values were assumed, 30 and 65 percent. The chart assumes a constant dry filter retention efficiency, but demonstrates how the cost savings increase when using filters with higher holding capacities. (The more expensive the clean, new filter is, the higher its holding capacity.)

Figure 15-6 clearly shows that the greatest pollution and cost reductions occur when the initial transfer efficiency is low and small improvements are made. At higher transfer efficiencies, the benefits are less pronounced. The next most important parameter is the filter’s holding capacity. Even though the cost of the filter increases with greater holding capacity, so do significant cost savings and pollution reduction.

Another issue that may require attention when assessing filter booths is PM_{IO} (particulate matter, the size of which is less than 10 microns). Industrial hygienists have established that particulates of such small dimensions often remain suspended in air for long periods, allowing workers to breathe them. Due to gravity, larger particles tend to settle to the ground. Many states are now including conditions in spray booth permits that limit PM_{10}. For instance, California requires Best Available Control Technology (BACT) when a new or modified permit requests an increase of 2.0 Ibs/day PM_{IO}. Both transfer efficiency and filter efficiency play dominant roles in determining whether or not the PM_{10} threshold will be exceeded. In addition, as transfer efficiency increases, the need is less to pay for high retention efficiency filters.

Filters are available that are made from expanded polystyrene. The advantage to these filters is that facilities can reuse them after carefully brushing overspray off the surface with a bristle brush. Hence, the same filters can function several times until they break or have otherwise degraded. The manufacturers also promote the idea that when a facility is ready to scrap a polystyrene filter, to immerse it into a 55-gallon drum of existing solvent/paint waste. Because of the strong solvents paint facilities use, the large filters quickly dissolve into small volumes of liquid, which must also be handled as liquid hazardous waste. Some companies argue that converting solid hazardous waste to liquid hazardous waste is counterproductive. A cost analysis will determine whether the conversion from solid to liquid is cost effective. Other companies argue that solvent and paint wastes exist anyway, and the small volume of added polystyrene is negligible when compared with the existing liquid waste. Finally, there are those who say that converting the solid filters into liquid hazardous waste is actually treating a hazardous waste, and that this is a violation of the Resource Conservation and Recovery Act (RCRA)

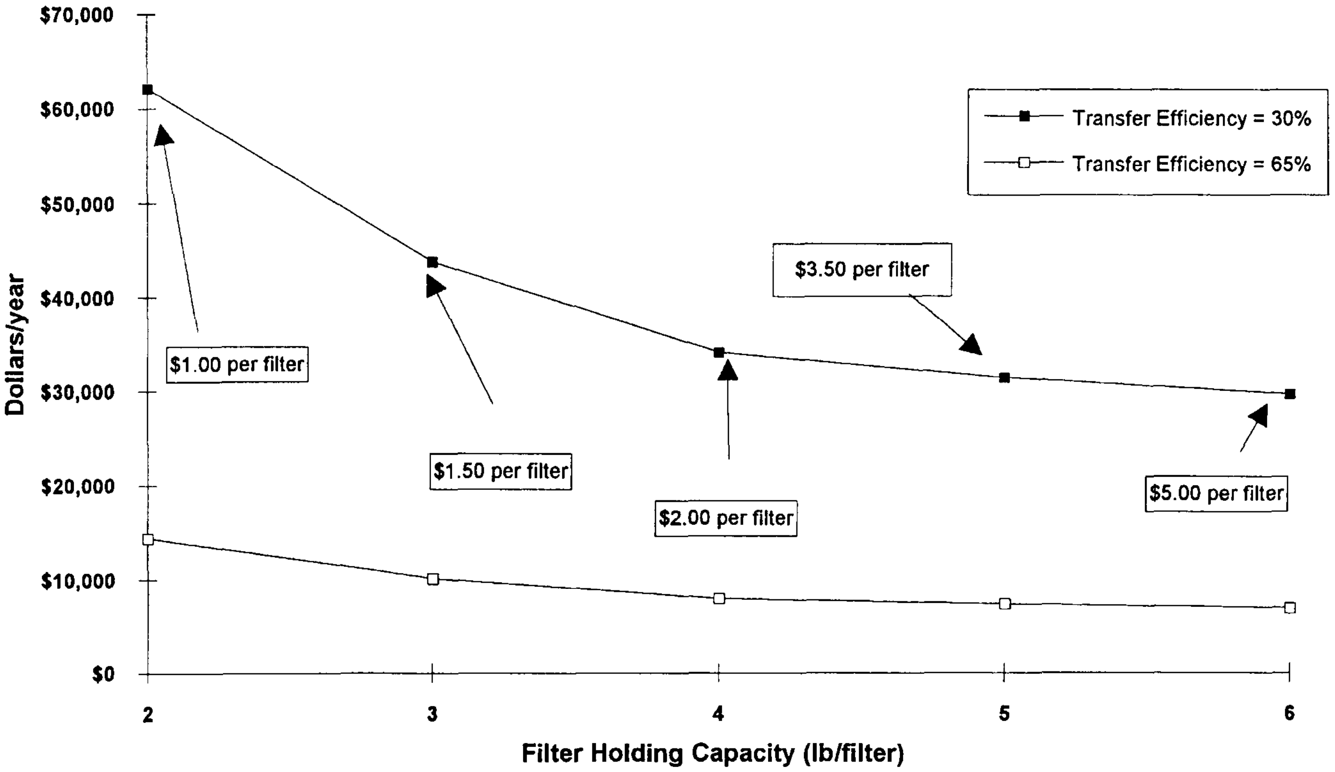


Figure 15-6. Cost of filter disposal based on holding capacity.

regulations. The journal Metal Finishing further detailed this complex issue in its May 1995 issue (4).

This is a controversial topic. Each company must decide its best option based on its own policy, the facts surrounding its individual situation, and its own state's regulations.

15.5 Water-Wash Spray Booths

The most important alternative to dry filter spray booths are water-wash booths. Instead of collecting overspray in the filter bank, a constant stream of water in an entrainment section scrubs the overspray from the air that the booth exhausts. Some water-wash booths are designed with a water curtain, but this is not a prerequisite. Most commonly, cross-draft and semi-down draft booths have water curtains while down draft booths do not.

Water flowing down the curtain collects much of the overspray, but the scrubbing action in the entrainment section is more important. In the entrainment section, fixed baffles force the exhaust air to constantly change direction and, as this occurs, the water scrubs the particulates from the air or they simply fall into the water trough.

Even after the overspray enters the water, it remains sticky and can plug up holes, nozzles, pipes, and pumps. In addition, it can form a deposit on the water curtain, slowly building up a layer that eventually impedes the smooth water flow down the curtain's face. With time, the water becomes contaminated with bacteria and requires disposal.

To prevent these unfortunate occurrences, the water needs treatment with one or more chemicals designed to detackify the overspray particles (i.e., remove the stickiness). Properly selecting the chemical(s) allows for long-term recycling of the water in the booth and reduces the frequency of the dumps. Paint facilities that implement regular and thorough maintenance programs run their booths for up to one year and more before exchanging the water in the trough.

15.5.1 Advantages

Water-wash spray booths are ideal when using large quantities of coatings, usually more than 5 gallons per day per square foot of face area. These booths are available in any type of booth design (i.e., small, large, open, closed, cross-draft, down draft, semi-down draft). Water-wash booths can effectively and efficiently remove particulates. Efficiency of approximately 99 percent is possible.

Unlike dry filter spray booths, the air velocity through the booth remains constant, provided that operators properly maintain the water trough. This helps to manage the overspray. In addition, facilities may choose to use chemicals (deflocculants) that either sink, float, or disperse the paint overspray.

Another benefit of such booths is that they provide essentially low fire risk.

15.5.2 Disadvantages

Like dry filter spray booths, water-wash spray booths do not remove VOC's, except for a small concentration dissolved in the water. Other issues also relate to their practicality.

For instance, they are more expensive to install and operate than are dry filter booths. Also, although they provide low fire risk, like dry filter booths, they require installation of a sprinkler system. Facilities, therefore, cannot realize cost savings in this feature. In addition, because of the water trough and entrainment area, they usually require slightly more space than a dry filter booth.

Maintaining water-wash spray booths also has some drawbacks. Operators must remove paint sludge from the water and dispose of it in order to prevent plugging of fluid passages. In addition, after running the booth for several months, the water will eventually require disposal.

Finally, water-wash spray booths require regular monitoring for:

- Level of water in trough
- Concentration of chemicals to detackify paint
- Foaming
- Rancidity

15.5.3 Selecting the Appropriate Chemicals

The correct choice of chemical deflocculant and defoamer is essential to the efficient operation of a water-wash booth. Some chemicals are available as solids or liquids. The more expensive chemicals detackify the paint sludge and dewater it, thus reducing the volume of sludge requiring disposal.

Available chemicals can sink, float, or disperse paint sludge. Choosing between them depends entirely on the design of the booth. For instance, if the booth draws water from the bottom of the trough and circulates it to the top of the water curtain, one would not want a deflocculant that causes the overspray to sink. In such a booth, paint sludge at the bottom of the trough would find its way into the pump and piping, eventually blocking these passages. In this situation, a deflocculant that allows the overspray to float or disperse in the water is best.

If, on the other hand, the booth draws water from the top of the trough and pumps water to the curtain, the preferred choice would be a deflocculant that sinks or disperses the paint sludge.

The most effective method for selecting a spray booth deflocculant involves sending a one quart sample of each coating to a chemical vendor, together with details of the booth design. The vendor can carry out tests to determine which chemical or combination of chemicals would remove the stickiness quickly and efficiently.

Depending on the type of coating they are using, operators may need to also use a defoamer. This prevents foam from building up at the water/curtain interface and allows the booth to continue functioning normally. If too much foam builds up, it can affect the pressure differentials that are necessary for the proper function of the booth.

Note that a chemical effective for one type of coating resin may not be effective for another. The type of coatings being spray-applied, therefore, dictates the selection of chemicals.

A problem can arise when applying more than one type of coating in the same booth. For instance, if operators apply high solids solvent-borne polyurethanes as well as water-borne alkyds in the same water-wash booth, possibly no single chemical, or even combination of chemicals would effectively perform. In such a case, operators may need to segregate the painting by applying the solvent-borne polyurethanes in one booth and the water-borne alkyds in another. While this may seem unreasonable, it may constitute the best solution to the problem.

15.5.4 Methods for Treating Water From Water- Wash Booths

One of the most important sources of hazardous waste from a water-wash spray booth is the water trough where the paint sludge collects.

Facilities can use several mechanisms to prolong the useful life of the water itself and minimize the disposal of the paint waste.

First, if the paint sludge sinks, operators can shovel out the booth, dropping the sludge into a 55-gallon drum. Invariably, however, the sludge is wet and contains a high percentage of water. Its disposal, therefore, generates an unnecessarily high volume of waste.

Alternately, if the sludge floats to the top, a weir placed at the top of the water level can collect it. Operators can then scoop it into a 55-gallon drum. Or, the sludge can feed into a centrifuge or a perforated drum that separates the sludge from the water. Provided that operators treat the water with a biocide to prevent rancidity, they can return it to the water trough for further use.

The most effective method for removing the sludge and minimizing the amount of water the sludge carries, however, is to use a polymer deflocculant that not only suspends the sludge as fine particles in the water, but also chemically dewaters it. This causes the sludge to no longer be sticky. It feels like wet sea sand. Filtering and removing this from the water is relatively easy using a drum filter, centrifuge, or hydrocyclone.

Finally, at least one company provides a process that takes the dry sludge (which has been dried in an oven), bakes and pulverizes it, and then sells the inert, non-hazardous waste for use as a raw material in the cement industry.

15.6 Baffle Booths

A baffle spray booth is a less common alternative to both dry filter and water-wash booths. In a baffle spray booth, the face of the booth has steel baffles that run the height of the booth and are several inches wide. The baffles usually overlap each other, forcing the air that passes through the booth to change direction in order to reach the back of the booth. When the air does reach the entrainment section at the back, the paint particulates it was carrying fall into a trough. Paint operators can then collect the paint from the trough for reuse.

These booths are much less frequently used than either dry filter or water-wash booths. This is because unless a company is reclaiming the paint, this booth offers no advantage. In addition, not all paints can be reclaimed. Although the recycling opportunities associated with baffle booths present strong pollution prevention benefits, most companies cannot use reclaimed paint and so cannot take advantage of these benefits.

15.7 Best Management Practices To Minimize Coating Defects in the Spray Booth

This section provides suggestions for minimizing the defects that result in reworks and rejects.. The most frequent coating defects that relate directly to the functioning of a spray booth include:

- Poor wrap when using electrostatic paints.
- Dust and dirt in the finish.
- Water spots in the finish.
- Haziness (blushing) that detracts from the gloss.
- Dry overspray on the finish.
- Non-uniform coating finish with gloss patches, orange peel, voids, etc.

Most of these defects often cause operators to perform rework or in some cases to altogether reject the workpieces they have coated. This of course leads to additional pollution and waste. Avoiding the defects then reduces unnecessary work and pollution.

15.7.1 Poor Wrap

This defect can derive from many possible reasons. Reasons that relate directly to the operation of the spray booth, however, are the lack of a proper ground and too high or turbulent an air flow through the booth.

To prevent poor wrap when using electrostatic paint, a facility operator must ensure that the spray booth has a proper ground. Changing the air flow might require assistance from an air ventilation expert.

15.7.2 Dust and Dirt in the Finish

This is probably one of the most frequent causes for reworks and rejects. Often, a fully assembled machine may require repainting because of dirt contamination. Unless the coating itself contains din the vendor did not strain or filter out, the problem usually results from poor spray booth operation. Facilities should take several measures and precautions to avoid this problem:

- Ensure that sanding or other dirty operations do not take place immediately outside the booth, as the booth blowers would draw in the dust.
- Ensure that the air filters at the air intakes of the booth are not dirty or have too large a mesh size.
- Ensure that the booth is operating under negative instead of positive pressure. In a closed booth, an air make-up system should provide the incoming air, which should more than compensate for the air the booth exhausts.
- When an air make-up system draws fresh outside air into the booth, ensure that its intake stack is not too close to the exhaust ducts from sanding and other dirty operations.
- Keep booth walls, floor, and ceiling free of loose, dry overspray or booth blowers may pry panicles loose, allowing them to fall onto freshly painted surfaces.
- Select the correct booth design.

Regarding the last bulleted item, as earlier sections of this chapter suggest, selecting the right booth design is essential. For instance, when coating large workpieces, use a down draft booth. Using a cross-draft booth would cause overspray to pass the sides of the freshly painted workpiece. If, however, using a cross-draft booth is unavoidable, minimize the problem by starting the painting operation at the back of the workpiece and moving forward to the filter bank.

15.7.3 Water Spots in the Finish

When using a water-wash booth, operators must properly clean the nozzles above the water curtain. Omitting this step creates the possibility for water droplets to settle on the painted finish.

15.7.4 Haziness That Detracts From the Gloss

This problem can occur under high humidity conditions when moisture vapor condenses on freshly painted surfaces and causes blushing. Clearly, this is more likely to happen with a water-wash booth than a dry filter one. In order to avoid this problem, remove the workpiece from the booth shortly after painting. If freshly painted surfaces remain in the spray booth overnight when the blowers are not on, humidity will quickly build up in the booth, increasing the probability of moisture condensation depositing on the cold metal surfaces.

If facilities cannot easily resolve this problem, they may need to convert the water-wash booth to dry filter.

15.7.5 Dry Overspray on the Finish

The most common reason for this defect is that the solvent is too fast. As the solvent flashes off during coating application, the overspray loses its wetness and cannot easily incorporate onto the freshly painted surfaces. While this problem is independent of the spray booth, a high air velocity in the booth will aggravate the situation. This, again, suggests that the air flow through the booth requires monitoring and controlling.

Another possible reason for dry overspray on the finish arises when more than one dry filter spray booth is being used. If the air flow within the larger spray room (incorporating the booths) is not uniform, overspray from one booth can settle on the freshly painted surfaces in another booth. This problem points to the need for proper air flow between all booths within the larger room. One solution is to provide each booth with its own air make-up unit.

15.7.6 Non-uniform Coating Finish With Gloss Patches, Orange Peel, Voids, etc.

Numerous causes exist for such defects, but those that are solely due to the spray booth are often associated with poor lighting. A vast number of spray booths are either poorly lit or have overspray almost totally concealing the glass panels that cover the lights. Providing a good looking finish is virtually impossible in such inadequately lit and poorly maintained booths.

Facilities should provide lighting not only from the ceiling but also from the sides of the booths. Most automotive, drive-in booths possess side lighting but very few three-sided, cross-draft booths have the same luxury. Investing in adequate lighting and regularcleaning of the cover plates will have a quick pay-back period in the form of better looking finishes and fewer touch-ups and re-works.

Aside from lighting, other suggestions for avoiding or resolving problems of non-uniform coating finishes follow:

- When using water-wash spray booths, strongly discourage spray painters from dropping paper cups, gloves, and other garbage into the water trough. They also must not empty leftover paint from quart or gallon cans into the trough. The chemicals cannot detackify such a large mass at one time, resulting in a sticky mess of paint that can plug fluid passages later.
- Ensure that sanding dusts cannot enter the spray booth. Before bringing a workpiece that has been scuff sanded into a spray booth, wipe down the entire surface with tack rags or wash it down with aqueous detergents. Sanding dusts that remain can contaminate freshly painted surfaces.
- As stated earlier, if using electrostatic spray guns, properly ground the booth and/or conveyor. Do not assume that they are grounded; only an ohmmeter can confirm grounding.
- Ensure you select the proper dry filter media for a dry filter booth. Selection guidelines appear in Section 15.4.3.

15.8 References

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Section 4
Problem Solving

Chapter 16
Problem Solving: Case Studies of Some Typical Paint Facilities

16.1 Introduction

This publication has tried to demonstrate how simple and often inexpensive strategies can resolve production and pollution problems. This chapter presents several realistic paint facility scenarios that reflect typical day-to-day production problems. Suggested solutions follow each presented problem. In almost all cases, the solution to a technical problem leads to improved quality of the finished product, reduced costs, and pollution prevention.

The three scenarios this chapter discusses are:

- Case Study #l: Flaking paint on tool boxes.
- Case Study #2: High reject rate and volatile organic compounds (VOC) emissions from aluminum lamp housings.
- Case Study #3: Start-up problems for automotive component manufacturer.

It should become clear to the reader that by improving the painting processes for the sake of efficiency and the quality of the finished product, pollution minimization becomes an automatic consequence.

16.2 Case Study #I : Flaking Paint on Tool Boxes

16.2.1 Background of Problems

Company A manufactures tool boxes that it sells to large retail stores. Customers have complained that the coatings on some, but not all of the boxes, have flaked off in small chips. Several thousand boxes, good and bad, have been returned for refinishing. Knowing about the usual coating process the company uses, of course, is essential.

The boxes are made of cold rolled steel. Surface preparation comprises a three-stage spray washing process plus a drying stage. These stages are:

- Stage #l: Degrease and iron phosphate
- Stage #2: Tap-water rinse (intermittent overflow)
- Stage #3: Tap-water rinse
- Stage #4: Dry-off oven at 230°F

Operators load the parts onto a conveyor immediately before they enter the first stage of the washer. After running through the washing and dry-off process, the conveyor then passes through the priming spray booth and finishing spray booth. The facility uses a fast-drying alkyd primer and topcoat system. The conveyor then loops the parts back to the spray washer where they are off-loaded before they can go through the washer a second time. The parts are sufficiently dry to be off-loaded.

Before going ahead with the refinishing process, Company A needs to identify which boxes are good from those which are likely to fail. By conducting an adhesion test, such as the Tape Adhesion Test described in American Society of Testing and Materials D3359, Method B, the quality control department can distinguish between the good boxes and those that will likely fail. In this test, a quality control operator applies a short piece (approximately 3 inches) of masking tape or, preferably, aluminum duct tape to the coating. After about 90 seconds, the tape is quickly removed by pulling back 180°. If coating does not peel away with the tape, the coating is good. If pieces of coating lift off onto the tape, the coating has poor adhesion, and the quality control operator considers it a failure.

The issues the company must address then are:

- After identifying the bad boxes, how should Company A strip the coatings?
- What are the likely causes of the inconsistent problem?
- What strategies should the company follow to improve the quality of the finish and to prevent similar occurrences in the future?
- Do any pollution minimization opportunities present themselves?

16.2.2 Possible Solutions

To identify and nullify the problem, Company A should first assess the whole process it will use to strip and recoat the boxes.

The stripping method must be fairly rapid because thousands of boxes require stripping. Also, the company must keep the cost to a minimum because the boxes themselves are inexpensive. If the stripping process is too costly, it no longer pays to refinish them.

Chemical stripping is a possibility but it requires several steps. Moreover, if any chemicals remain on the surface or if water ingresses between spot-welded plates, paint failures can re-occur. Air, water, and waste pollution also are major negating factors.

Mechanical stripping in the form of abrasive blasting using grit, aluminum oxide, or another such abrasive probably offers the greatest advantages. While the process should be relatively fast, the abrasive cannot be too coarse or it will deform the boxes, and misalignment of the lids is a serious concern. The company might seriously consider plastic bead blasting because the beads are unlikely to damage the metal surfaces. Moreover, the beads can be recycled and only the paint chips require disposal. If the waste passes the TCLP tests, the company can dispose of it as non-hazardous solid waste.

Although a three-stage washer is not ideal for treating a cold rolled steel substrate, it is usually adequate for the intended purpose, namely to coat the tool boxes. The process requires careful control, however, to ensure good paint adhesion. Operators must perform quality control checks on the temperature of the first stage (per the chemical manufacturer's recommendations), on the pH and free acid of the bath, and on the contact time between the steel and the chemical.

Poor rinsing practices can also contribute to the failures, specifically with a three-stage process. In this scenario, Stage #2 overflows on an intermittent basis. This suggests that contamination from Stage #1 can build up to an unspecified level before the water is diluted with make-up tap water. Company A, therefore, should provide for continuous overflow. In addition, the company's manufacturing engineers should study the hanging of parts from the conveyor to minimize drag-out from Stage #l to Stage #2.

Stage #3 is also a tap-water rinse. This can pose a problem if the tap water contains a relatively high concentration of dissolved solids. In an ideal process, the second rinse tank includes a sealer that consolidates the phosphate film. Moreover, deionized water works better than tap water. In reality, however, it may not be cost-effective nor necessary for Company A to incur the expense of a deionized water generator. Tool boxes are not the type of commodity that warrants a sophisticated finish. At the very least, though, Stage #3 should be a nonchromate seal rinse, for which the added cost is minimal. (A chromate seal rinse often offers better protection, but poses an environmental problem.)

The next stage uses the dry-off oven. In this scenario, the dry-off oven temperature is too low. For rapid drying of the wet parts, the oven temperature should be greater than 300°F. The low temperature allows parts to flash rust even before they have left the oven.

A quick drying alkyd system has the advantage of precluding the need for a paint baking or curing oven. The compromise Company A makes when selecting such a coating, however, is that the coating film is often hard and brittle. Slower drying alkyds tend to have better flexibility and adhesion properties, but to keep up with production speeds the company might need to install a force-dry oven. The company should, therefore, re-examine its selection of coating.

Although each step in the process has been reviewed, one final important factor remains: the conveyor system itself is associated with problems. The conveyor passes through the spray washer, dry-off oven, and the two paint spray booths. A common problem resulting from this configuration is that the spray painter in either of the spray booths has the ability to start and stop the line at will. This occurs during coffee and lunch breaks, or when the spray painter needs to perform another function, such as filling the pressure pot with fresh coating. When the conveyor stops, several of the parts still in the spray washer may be between stages. If the stoppage lasts for more than a few minutes, the parts might start to flash rust or may receive too heavy a phosphate coating. Parts that have proceeded through the rinse stages but have stopped short of the dry-off oven will be left wet for too long. Quick drying is critical to prevent flash rusting. This intermittent action would also explain why only some, and not all, tool boxes fail. To avoid these problems, Company A should consider one of two options. The company should prohibit anyone from stopping the conveyor until all of the parts in the spray washer go through the oven. Alternately, Company A should break the conveyor into two separate conveyors: one solely dedicated to the spray washer and dry-off oven, the other dedicated to the spray booths. Operators can either transfer the parts from one conveyor to the other manually, or the company can install a power-and-free conveyor to pass through the spray booths.

A power-and-free conveyor has two or more segments, each separated from the other. For instance, the first segment might be a short length of continuous loop conveyor that forms a closed circuit. The second segment may comprise racks that receive parts from Conveyor #l and transfer them laterally. Finally, Conveyor #3 might pick up the parts from Conveyor #2, and transfer the parts along another continuous loop conveyor. All three conveyors can be moving at different speeds and in different directions (see Figure 16-1). The transfer from one conveyor to the next is usually automated.

16.2.3 Pollution Prevention Opportunities

This case study has suggested several strategies that would not only solve the immediate problem, but also

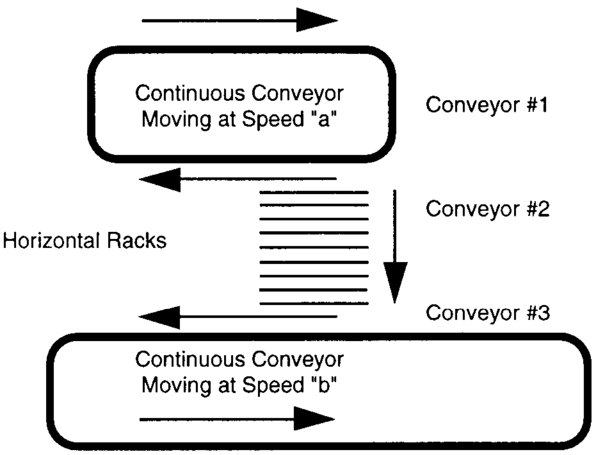

Figure 16-1. Example of power-and-free conveyor.

lead to better management practices. If the company is only interested in solving the immediate problem, then it would need to experiment to identify the specific cause of the failures. The company could inexpensively improve so many existing practices, however, that it would definitely benefit by overhauling the entire process. This type of overhaul would improve the company's product, reduce the number of rejects and refinishes, and ultimately lead to dramatic pollution prevention (mostly in the form of fewer rejects and refinishes).

In solving its catastrophic production problem, Company A can substantially reduce its air, water, and waste pollution. The described options that offer the best opportunity to improve the process and reduce pollution include:

- Use mechanical stripping via plastic bead blasting.
- Enforce stricter quality control in three-stage washer.
- Provide for continuous overflow in rinse stages.
- Minimize drag-out between washer stages.'
- Use deionized water or at least a nonchromate seal rinse.
- Increase baking temperature in dry-off oven.
- Switch to slower drying alkyd or install force-dry oven.
- Prohibit operators from turning off conveyor in mid-process or divide conveyor into two.

16.3 Case Study #2: High Reject Rate and VOC Emissions From Aluminum Lamp Housings

16.3.1 Background of Problems

Company B manufactures long aluminum lamp housings (or covers) for fluorescent lamps. They are long 12-inch diameter tubes cut in half longitudinally. Some housings can be as long as 16 feet. Architects specify these products for shopping complexes, banks lobbies, insurance companies, hotels, and other high-profile buildings and institutions.

Because of the housings' high visibility to the public, Company B uses a two-component high solids, low-VOC polyurethane. The polyurethane is pre-mixed at the beginning of a job and operators mix sufficient coating for one shift's work. Generally, they do not mix more coating than the job requires. Because some of the orders are large, the paint shop often uses one color for an entire shift. Sometimes, however, coating several small jobs on the same day requires more than one color. Spray painters use airless spray guns because the lamp housings are long and the spray painters must keep up with the fast production speed of 15 feet/minute.

Quality control engineers reject approximately 10 percent of all housings because of color and gloss patches (differences), which are clearly visible when viewing the finished products from a distance. The rejected housings return to the finishing shop where operators scuff-sand them to a uniform finish. Operators remove the sanding dust with tack rags, and then wipe the sanded finish with a strong solvent to soften the cured finish and allow for the application of a fresh coat of polyurethane. In most cases, engineers approve the refinished housings for sale. A few require refinishing a second time. In addition, some customers have returned housings several months or even 18 months after original manufacture because the coating peeled off in sheets.

These problems have caused two major consequences for Company B. The cost of the added coatings, wipe solvents, hazardous waste disposal, and labor required to refinish the reject and returned housings has had a disastrous effect on the profitability of the company. In addition, VOC emissions are several tons over the permitted annual cap. The company must resolve the following issues in order to solve its problems:

- What are the probable causes for the color and gloss patches?
- What strategies can minimize or even eliminate the rejects and returns?
- What pollution minimization strategies can get the company back into compliance with its air quality permit and further reduce the final cost of the housings?

16.3.2 Possible Solutions

Given the problems Company B faces, its search for solutions should concentrate on three different areas:

- Spray gun options
- Viscosity management

- Coating selection

Each of these factors contributes to one or all the problems the company faces.

16.3.2.1 Spray Gun Options

The primary cause of the color and gloss patches (differences) is that the housings receive an uneven coating. Film thickness measurements of the coating would probably show that a significant variation exists over the length of the housing. Two primary factors may be responsible for this:

- The airless spray gun is inappropriate for this job.
- For the rejected lamp housings, the viscosity of the high solids, two-component polyurethane is probably too high.

This section discusses the spray gun possibilities. The next will cover viscosity.

An airless spray gun is appropriate for jobs in which the spray painter must move quickly and apply the coating in one application. This gun, however, may not be appropriate when a high visibility product needs to have a uniform film thickness. This is particularly true when applying high solids, low VOC coatings because the spray painter does not have sufficient control of the gun. If the coating had a lower solids content, the airless gun might be able to apply a high-quality finish, but under such circumstances the painter might have difficulty preventing runs and sags. High-quality finishes require excellent atomization. The more appropriate guns would be conventional air atomizing, HVLP, and electrostatic.

The conventional air atomizing gun would almost certainly give the desired finish but transfer efficiency tends to be lower than for other gun options. The poorer efficiency dramatically increases the coating, solvent, and hazardous waste costs, and significantly increases VOC emissions into the air. This gun, therefore, would not prove to be the best option.

Some HVLP guns would also provide the desired finish. Company B, however, may need to shop around and experiment with different HVLP guns before making a final selection. This is because not all guns will give the desired results. If the company can make an up-front investment, the HVLP guns that would probably give the best finishes are those that use a turbine to generate the atomizing air. Only on-site testing can demonstrate justification of this extra expense.

Electrostatic guns would also probably satisfy the company's requirements. In addition, airless or air-assisted airless electrostatic guns allow for faster application speeds.

If using electrostatic guns, the company must ensure a proper ground each time a housing is coated. When properly used, electrostatic guns can give the highest transfer efficiencies compared with all other guns. The additional capital costs the company would incur to purchase such equipment can have a rapid payback.

Because of the simple geometry of the housings and the fast production line speeds, the company might also want to investigate the use of high-voltage electrostatic bells. These might prove to be an ideal choice because they lend themselves to automation and can achieve transfer efficiencies of greater than 90 percent.

16.3.2.2 Viscosity Management

Although high solids polyurethanes have relatively low viscosities compared with other coating resins of the same solids content, they nevertheless require proper atomization in order to avoid color and gloss patches. In this scenario, operators pre-mix the coatings at the beginning of the shift. This implies that as the day progresses, the viscosity slowly builds up until it approaches its pot life. Although, in this case, the coating does not seem to actually reach its pot life, the viscosity of the pre-mixed coating definitely increases.

Rather than pre-mix coating for large jobs, the company should consider the efficacy of plural-component metering and mixing equipment. The primary advantages are that the viscosity of the coating would remain constant all day, and at the end of the shift, operators would only need to clean the unmixed coating in the fluid line between the mixing manifold and the spray gun. This equipment would drastically reduce hazardous waste from pre-mixed coating. The most important disadvantages are that the equipment is relatively expensive, $5,000 to $15,000 depending on the system, and it is only feasible to install such equipment for relatively large jobs that use well over 1 gallon per day.

For smaller quantities, pre-mixing is more economical. Even if the company decides to invest in plural-component equipment, the spray painters would still need to pre-mix coatings for the smaller jobs.

Another inexpensive method for managing viscosity is to mix smaller quantities. Instead of pre-mixing the entire day's coating requirements, the operators should mix smaller quantities, perhaps one batch before lunch and another after. This would minimize the viscosity differential that occurs while the mixed coating is waiting to be used.

An additional strategy is to keep the pre-mixed coating cool, but not below the dew point as this will cause condensation to diffuse into the coating and produce visible white gel particles.

The problem of the coating peeling off in sheets also probably relates to viscosity management. This problem suggests that the spray painters added solvent to the pre-mixed polyurethane to prolong its pot life. This is a very poor practice because the coating can entrap the extra solvent while it is cross-linking. Entrapped solvent often remains in the coating for months and years, and in many cases can lead to coating delamination. This probably occurred in this scenario.

16.3.2.3 Coating Selection

If the problem of color and gloss differences continues to occur, the company may need to search for another coating, or ask its vendor to consider reformulating the product to improve its application properties. Not all polyurethanes are alike, and converting to a different formulation could possibly solve the problem.

Another consideration for Company B is switching to one of the new low-VOC water-borne polyurethanes that are now becoming available. The company may benefit from sampling a few formulations and testing them for their application and physical properties. Usually, water-borne coatings have a lower solids content than solvent-borne high solids coatings; therefore, this might solve the current problem. The company's total annual VOC emissions would also probably drop by at least 20 percent.

Alternately, the most effective strategy by far for minimizing pollution is to convert from liquid polyurethanes to powder coatings. The lamp housings Company B manufactures are ideally suited to these coatings because of their fairly simple shape. After such a conversion, the company would emit essentially no VOCs, and it can melt the excess and unused powder coating into solid blocks. If the blocks pass the TCLP tests, the company can dispose of them as non-hazardous waste.

In addition to pollution prevention, switching to powder coatings would offer other benefits as well. The simple shapes of the housings lend themselves to an automated coating application, a factor that makes powder coatings an even more attractive option. Moreover, the color and gloss patches experienced with the liquid high solids coatings are less likely to occur with powders because they tend to produce more uniform film thicknesses.

Of course, in order to convert from liquid to powder coatings, Company B would need to reassess its entire coating facility. One cannot simply swap one coating for another. The existing spray booths would require replacement with special powder coating booths that are designed to capture and recycle the oversprayed powder. The guns and ancillary equipment would also need replacement. In addition, the oven must have the capability to cure the powders for 8 to 20 minutes at 325^{o} to 400°F. The existing surface preparation process may be adequate, but the company would need to confirm this.

To make such a major conversion requires capital and time. Most large companies wait for a scheduled shutdown period before switching the equipment. In addition, the company must train its operators to use powders, and must write and implement a new set of quality control procedures. For this scenario, it seems likely that Company B would solve its current problems and receive a payback on its investment. It can also expect, however, new problems unique to powders, although these too would be resolved with time.

16.3.3 Pollution Prevention Opportunities

In rectifying its problems, this company can automatically enjoy the benefits of reduced pollution and accompanying cost reductions.

If the company decides to stay with liquid coatings, choosing a high transfer efficiency spray gun would result in considerably less overspray on the spray booth filters, and on its floor and walls. Not only does this immediately translate into maintenance labor savings, but the company would need to discard fewer filters and, thus, also purchase fewer. As was discussed in Chapter 9, coating usage and emissions decrease when transfer efficiency increases. If transfer efficiency is generally low, e.g., 30 to 40 percent, a small improvement in application efficiency can result in a significant reduction in all forms of pollution as well as in costs. Hidden benefits would be improved labor conditions, better pride in the finished product, and improved customer/vendor relations and credibility.

If Company B finds that its situation lends itself to using plural-component metering and mixing equipment, it can realize great pollution prevention and cost benefits. Companies that have implemented an in-line metering and mixing system for plural-component coatings have reported significant savings in hazardous waste disposal. Because the cost to dispose of a 55-gallon drum of liquid hazardous waste can be as high as $500 to $600, the equipment change obviously can quickly generate a payback.

If Company B were to replace liquid coatings with powders, it would essentially eliminate all forms of its pollution. This cost reduction alone might justify the capital outlay it would require to tear down the old system and install the new one.

16.4 Case Study #3: Start-Up Problems for Automotive Component Manufacturer

16.4.1 Background of Problems

Company C manufactures components for the automotive industry, and its paint finishing shop is a brand new facility. Numerous start-up problems are preventing the company from getting its finished components to the market, and environmental problems are already surfacing. Before introducing the problems, a brief background of the facility's process follows.

Several types of substrates require coating by this company. The facility cleans and treats components made of cold rolled steel in a 7-stage zinc phosphate line designed to give a heavy zinc phosphate coating of 400 mg/ft^2 to prevent corrosion. Alternately, operators treat aluminum parts with a chromate conversion coating. All metal substrates then receive one coat of an epoxy basecoat. Operators then apply a clear coat of two-component polyurethane over the basecoat.

All plastic housings are scuff-sanded and washed with a mixture of methyl ethyl ketone (MEK) and isopropanol before being primed with an epoxy sanding primer. Thereafter, operators sand the primer to a smooth finish with 240-grit to 400-grit paper to hide all swirl marks in the plastic molding. The plastic parts then receive a conductive primer.

All of the spray booths in the facility are of the cross-draft, dry filter type. Operators change the filters as soon as the magnahelic gauges on the sides of the booths show a pressure differential of 0.5 inches. Because coating usage differs for each booth, the filters are not all changed at the same time.

One large finishing room contains all of the spray booths. One very large air make-up unit supplies all of the air to the booths. Strict procedures prevent unauthorized employees from entering the finishing room. Those who do enter must wear cotton booties, lint-free coveralls, and lint-free disposable caps to cover their hair. In the booths, electrostatic turbo bells held by robots or reciprocators actually apply the coatings.

The problems that need addressing are:

- Heavy sludge from the zinc phosphate pretreatment tank requires disposal of relatively large volumes of waste.
- Large volumes of rinse water from the spray washer require treatment before being discharged to the publically owned treatment works (POTW). In addition, the POTW is complaining because the facility was never designed to handle so much water, and is asking Company C to urgently address this problem.
- The finished steel components and aluminum parts do not have the same gloss, even though they use the same basecoat and clear coat. For some colors, the gloss difference also appears to the observer as a color difference. This is a major problem when steel and aluminum parts are adjacent to each other on the same assembly.
- Most finishes are marred with dust and dirt despite the fact that all personnel wear clean lint-free clothing and the company has made every effort to keep dust out of the finishing room.
- Dry overspray mars some of the clear coats. Viewing the parts under a microscope suggests that the overspray may come from the basecoat booths.
- Although the company uses electrostatic turbo bells, the transfer efficiency is too low for such guns. Consequently, VOC emissions already approach the permitted cap and are almost double what was originally estimated when the permits were applied for. A consequence of the poorer than expected transfer efficiency is that the filters become clogged more frequently and require disposal. Because the company has determined that the overspray from at least one of the coatings fails the TCLP test, the policy is to dispose of all the spent filters as solid hazardous waste. In a typical month, the company disposes of ten 55-gallon drums of spent filters, and this significantly increases the total cost of running the paint shop.

16.4.2 Possible Solutions

Zinc phosphates do produce sludge, and this is one of the disadvantages that end-users must accept when they specify a zinc phosphate system. If the sludge build-up is higher than expected, then end-users may need to evaluate several operating parameters. For instance, causes for the high sludge build-up may include:

- The concentration of the bath may be too high
- The temperature may be too high
- The tank may be over-agitated
- Parts may be in the phosphating stage for too long
- The pH may be incorrect

Company C should call its chemical supplier and ask a technical representative to troubleshoot the problem. The supplier will probably find at least one of the parameters out of specification. This implies that better process controls may need to be in place, and operators may need to monitor the parameters more frequently.

The large volumes of water the facility treats and discharges may be warranted, or they may be excessive. In order to assess this, the company must address several questions:

- Are the fabricated metal surfaces more contaminated than they should be? If so, how can the company minimize their contamination loading?
- Is the drag-out from the process tanks to the rinse tanks too high?
- Has the rinse water overflow rate been correctly calculated?

- Is the company maintaining the concentration of the rinse tanks at unrealistically low levels?
- Are the rinse tanks designed to achieve optimum counter-flow characteristics?
- Why can't the company treat and recycle the water in a closed loop system?

The gloss differences between the steel and aluminum parts may result from a difference in the surface finish of the two metals or from the zinc phosphate coating.

If the two metals have different surface finishes, the company may need to specify a different finish, or if that is not possible, operators can apply a sanding primer to the rougher of the two metals. This option, however, would add significantly to the cost of the finishing process. Not only does it require an extra coat, but all components would require sanding to a smooth finish before applying the basecoat.

Some zinc phosphates produce macro-crystals that absorb the coating, thus giving the appearance of lower gloss. The automotive industry tends to purchase zinc phosphates that produce micro-crystals. For such systems, one would not expect to see a noticeable gloss difference between the steel and aluminum coated parts.

Keeping dust and dir-t out of a painting facility is extremely difficult. In this scenario, the company has apparently taken precautions to keep the employees from bringing contaminants into the facility; therefore, other possible causes may be:

- The spray room may be operating under negative pressure.
- The air make-up unit may be pulling in dust-laden air.
- The coatings may contain dir-t that was not previously filtered out.

If the spray room is at times operating under negative pressure, the vacuum can pull dust and dirt from adjacent areas of the factory.

The air make-up unit, which has obviously been designed to pull a large volume of air into the spray room, may be pulling in dust-laden air from the exhaust stacks of other operations (specifically the sanding operation). If the intake filters to the air make-up unit have too coarse a mesh, or if the pressure differential across the filters is too high, the dust and dir-t could easily enter the spray room.

The possibility also exists, although it is less likely, that the coatings themselves contain dirt that was not filtered out prior to use. End-users can easily check this by taking a spatula and dipping it into the pressure pot. As the paint runs off the end, one can spot small dirt particles in the wet coating. If these particles are present, using simple filtering techniques can usually solve the problem.

The problem of overspray from one spray booth affecting the finishes in another booth may at first seem baffling. Bear in mind, however, that all of the spray booths are dry filter booths. Thus, as each filter pad collects overspray, the pressure differential across the filter bank increases, and the air flow into the exhaust stack decreases accordingly. Since one air make-up unit feeds all the booths, the air flow within the larger finishing room is constantly changing. Some filters become more plugged with overspray than others, pressure differentials constantly change, and air movement is never constant. As soon as operators change the contaminated filters in one spray booth, this booth suddenly draws its maximum capacity of air, which may entail drawing air from another spray booth with clogged filters. In addition, sometimes one or more booths may be idle for a few hours of the day. Then, as operators turn on the blowers, the booth suddenly draws air, once again changing the dynamics of the entire finishing room.

The most effective method for eliminating this problem is to provide a separate air make-up system for each booth. This would ensure that the air make-up is always sufficient to supply the needed volume of air. If too much of a positive pressure develops, however, the air would once again start affecting other booths.

The problem of improper ventilation is not easy to solve, and the company may need to hire ventilation consultants to rethink the system.

The final issue for this company, transfer efficiency, is one of the most important parameters that affects VOC emissions into the air, as well as the volume of hazardous waste generated. Because electrostatic turbo bells are known for their high efficiencies, the company must look at other factors that may be causing the problem. These include:

- Inconsistent air flow
- Improper grounding

The company has already established that the air flow in the finishing room is not laminar and changes direction from one moment to the next. The efficiency of turbo bells is extremely sensitive to air flow in the booth. Even when air flow is (correctly) toward the filter bank, if the velocity is too high, the air carries the paint particles away from the parts being painted and into the filters.

Alternately, if the parts are not properly grounded, or if the paint does not have the proper polarity, the turbo bells cannot apply the coating electrostatically.

A few quick experiments can determine why the turbo bells are not achieving the desired transfer efficiency.

Since this is a major factor affecting VOC emissions and hazardous waste, the company should investigate this problem to the fullest so that it can achieve the maximum efficiency.

16.4.3 Pollution Prevention Opportunities

Pollution prevention opportunities for Company C abound. First, if it could reduce the amount of solid sludge waste from the zinc phosphate treatment, which is in itself a pollution prevention measure, the company would also be extending the life of the bath. This would necessarily reduce the total volume of water that Company C needs to treat and dispose of occasionally.

If the company installs a closed loop system (i.e., by treating all the effluent water from the treatment system and then recycling it), its cost for city water would drop. No guarantee exists, however, that this would lead to an overall cost reduction, particularly if the city tap water is inexpensive and the cost for in-house treatment is high.

The pollution prevention and cost benefits associated with overcoming the poor spray booth conditions and the inappropriate choice of spray guns are very similar to those provided in Case Study #2.

If Company C can solve the critical problem of turbulent air flow in the spray booths, total air emissions would immediately drop, as would the generation of unnecessary hazardous waste, both in the form of used dry filters and waste paint.

Clearly, the company has little choice but to resolve its problems if it wants to remain competitive and stay in business. By solving its production problems, it will automatically enjoy many unexpected cost benefits, and it will dramatically improve the environment of the community.

16.5 Conclusion

This chapter has presented three typical scenarios. All of them relate to day-to-day production problems in a coating facility, and to a large extent the problems have little to do directly with the environment. The suggested solutions, however, show that once a company implements better management practices, the rate of reworks and rejects diminishes, as do the parameters that affect the quantity of coatings and solvents used. It is a win-win situation for all parties:

- The company enjoys fewer environmental/regulatory problems, more efficient processes, greater productivity, greater competitiveness in the market, and lower finishing costs.
- The customer gets a higher quality product.
- We all enjoy dramatically reduced air, water, and waste pollution.

A reader who wants to keep updated with current coating and equipment technologies can access many monthly technical journals that are often available free of charge. Some address the scientific community and are very technical. Alternately, other journals are solely pragmatic and target finishing engineers, paint supervisors, and painters who are looking for any hints that will make their jobs easier.

Readers can often find in the literature solutions to problems such as those this chapter has discussed. Failing that, the reader has access to chemical, coating, and equipment vendors. When the problem is too complex or crosses many different fields, consultants can be retained. The end-user can usually find one or more avenues to resolve problems. As a consequence to solving these production problems, the end-user will be contributing to pollution prevention.

Appendixes

Appendix A
Selected List of Suppliers of Aqueous and Semi-aqueous Degreaser Formulations and Equipment*

AQUEOUS EQUIPMENT SUPPLIERS
LARGE UNITS

NAME	COMPANY	TYPE	COMMENT
Spray Washer	New Pac, USA P. O. Box 1461 Palatine, IL 60078 312-541-3961	Inline, Overhead Monorail	Constructed of Composite Non-Corroding Materials
ESTECH C-15154 C-15158	Equipment Systems Technology P. O. Box 550 Findlay, Ohio 45840 419-424-4239	Heavy Duty Monorail (C-15154) or Conveyorized (C-15158)	Cleans & Phosphates Aqueous Cleaners
Final Phase Industrial Parts Cleaners	Final Phase 23540 Pinewood Warren, MI 48091	Conveyorized Monorail or Drum Aqueous Cleaners	Existing Equipment Modification Services Available
Aqueous Parts Cleaner	Ransohoff N. 5th St., at Ford Blvd. Hamilton, OH 45011 513-863-5813	Inline Monorail, Conveyorized Automated, or Batch. Complete Line of Equipment, Small to Large	Controlled Spray Impingement System. Complete Design Services Available

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AQUEOUS/SEMI AQUEOUS CLEANERS

CLEANER	SUPPLIER	TYPE	USE	POTENTIAL PROBLEM
Bio Act EC7	Petrofirm, Inc. Specialty Chemicals 5400 First Coast Hwy. Fernandina, FL 32304	Terpene & Esters	Electronics & Parts Cleaners	Flammability
Simple Green	Simple Green P. O. Box 880135 El Paso, TX 88588-0135	Terpene	Metal Cleaning	Flammability Treatability
Daraclean 220, 282, 283	W. R. Grace 55 Hayden Ave. Lexington, MA 62173 404-691-8646 800-232-6100	Alkaline With or Without Glycol Ethers	Metal Cleaning & Electronics Parts Cleaning	Corrosivity Silicates Immediate Rinse May Be Required
Quaker 624 GD	Quaker Chemical Co Elm & Lee Streets Conshohocken, PA 19428 215-832-4000	Alkaline	Immersion Ultrasonic	Corrosivity Silicates
Turco 3878 6753 6778 4215 -NC-LT	Atochem - NA 3 Parkway Philadelphia, PA 215-587-7000	Emulsion w/agitation (3878) Non-Chromated Alkaline (6778)	Replace Vapor Degreasing	Chromates from 3878 LF-NC Non-Chromate Form

CLEANER	SUPPLIER	TYPE	USE	POTENTIAL PROBLEM
Coors Bio-T	Spectro-Chemical Lab Division Coors Porcelain Co. 600 Ninth Street Golden, CO 80401 303-277-4254	Terpene	Metal Cleaning	Flammability
Ridolene 1025	Parker Amchen 32100 Stephenson Hwy Madison Heights, MI 48071 800-222-2600 Ext. 286	Alkaline (NaOH)	Vapor Degreaser	Safety
TD 1414-F-B	DO	Petroleum Solvent	Parts Cleaning & Paint Prep	Flash Point
3HA-HF	Arsol	Terpene Hydrocarbon	Lacquer Stripper	Flash Point
Kwik Dri 66	Ashland Chemical, Inc. Industrial Chemicals P. O. Box 2219 Columbus, OH 43216 614-889-3627	Aliphatic drocarbon troleum Distillate	Paint Thinner	Flash Point
Actrel 3338L, 3349L, 3360L, 1160L	Exxon Chemical P. O. Box 5200 Baytown, TX 77522 713-425-2115	Hydrocarbon	Drawing Oil, Cutting Oil, Grease	VOC's Flammability
Exxate 800	Exxon Chemical P. O. Box 5200 Baytown, TX 77522 713-425-2115	Hydrocarbon	Drawing Oil	VOC's Flammability

CLEANER	SUPPLIER	TYPE	USE	POTENTIAL PROBLEM
Rust Corrosion Remover CT-3/CT4	Chem-Tech International Mid America Chem Corp. 4701 Spring Road Cleveland, Ohio 44131 216-749-0100	Mineral Acids/ Glycol Ethers	Remove Oxidation Rust. Requires Pretreat with CT.1	Safety
CT1/2	Do	Acid Hydrocarbon	Precleaning Multi-Substitutes	Preclean CT1, Rinse CT2, Dry Flammability
XUS11269.01	Dow Chemicals & Metals 2020 Dow Center Midland, MI 48674 517-636-3029	Surfactants With Corrosion Inhibitors	Light Oils/Grease	Safety Corrosion of Some Metals
XUS11268	Dow Chemicals & Metals 2020 Dow Center Midland, MI 48674 517-636-3029	Semi Aqueous Glycol/ Hydrocarbons	Light Oils, Metal Films	Odor - Must Be Incinerated for Disposal
XUS-11267	Dow Chemicals & Metals 2020 Dow Center Midland, MI 48674 517-636-3029	Cold Cleaner w/Hydrocarbons	Oils, Grease	Toxicity, VOC's Treatment
Action Bioclean	Action Products, Inc. 2401 W. First Street Tempe, Arizona 85281 602-894-0100	Water Biodegradable	Metals Parts Wash	?

CLEANER	SUPPLIER	TYPE	USE	POTENTIAL PROBLEM
Teile Reinigung Smittel 09	RAASM USA P. O. Box 150146 Nashville, TN 37215 615-255-7434	Alkaline	Steam, Pressure Cleaning	Safety
SW-528	Lubrichem, Inc. P. O. Box 30665 Raleigh, NC 27622 919-839-1211	Alkaline KAOH pH13	Metal Cleaner	Aluminum Alloys Safety
R. B. Degrease	Environmental Technology Sanford, FL 32771 407-321-7910	Sulphanate	Metal Cleaning	Foaming
BioClean	Kester 515 E. Touhy Ave. Des Plaines, IL 60018-2675	Alkaline	Printed Circuit Boards	Safety
Citrex Citra Safe	Inland Technology 2612 Pacific Hwy, E. Tacoma, WA 98424 206-922-8932	Terpene	Methylene Chloride 1,1,1 Vapor degreasing	Flammability
Axarel 38/52	Dupont Chemicals Chestnut Run Plaza P. O. Box 80711 Wilmington, DE 19880-0711	Hydrocarbon	38- Electronics 52-Grease Metal Cleaner	Flash Point
RMA & RA Flux Remove & Cleaner	Mid America Chemical Cleveland, OH 44131 216-744-0100	Alkaline & Surfactants	Circuit Boards	Treatment

CLEANER	SUPPLIER	TYPE	USE	POTENTIAL PROBLEM
P F Degreaser	PT Technologies, Inc. 108 4th Ave., South Safety Harbor, FL 34695 813-726-4644	Low Aliphatic Hydrocarbon/ Terpene	Substitute for 1,1,1 Cable & Metal Cleaner	Combustible
Arconate TM 1000	Arco Chemical 3801 West Chester Pike Newtown Square, PA 19073 1-800-321-7000	Propylene Carbonate	Replace Methylene Chloride	Safety Requirement
Gillite 0650	Man-Gill Chemical 2300 St. Clair Ave. Cleveland, OH 44117 1-800-627-6422	Alkaline	Metal Cleaning	Safety
Hurricane Cleaning Compounds	Midbrook Products 2080 Brooklyn Road Box 867 Jackson, Mich 49204 517-787-3481	Alkaline	Metal Cleaning	Safety
Aquaease	Hubbard-Hall, Inc P. O. Box 790 Waterbury, CT 06725-0790 203-756-5521	Alkaline, Terpenes and/or Hydrocarbons	Vapor Degreasing Alternative Cleaners	Process Specific
EZE 267D	EZE Products, Inc. P. O. Box 5744 Greenville, SC 29606 803-879-7100	Alkaline	Steel Parts Dip Tank	Safety

CLEANER	SUPPLIER	TYPE	USE	POTENTIAL PROBLEM
Brulin 815 GD 815 GR	Brulin Corporation	Alkaline	Metal Cleaning	Mild Corrosivity Silicates
Alka - 2000	Calgon Vestal Labs. 7501 Page Avenue St. Louis, MO 63133 800-648-9005	Potassium Hydroxide	Ferrous Metals Cleaning <u>Only</u>!	High pH Safety and Handling
(1) DOT 111/113 (2) Omni Clean H. D.	Delta - Omega Technologies, Inc. P. O. Box 81518 Lafayette, LA 70598-1518 318-237-5091	(1) Proprietory "Surfactants System" (2) "Water Based" Proprietary	(1) Metal Cleaning (2) Heavy Oil Buildup All Surfaces	(1) None Listed In MSDS. High Concentrations could cause Aquatic Toxcity (2) None Listed
Glidsafe Family	GLIDCO Organics P. O. Box 389 Jacksonville, FL 32201 904-768-5800 800-231-6728	Terpene Blends	Ink Removal, Hand Wiping, Emulsion Cleaning	Flammability Treatment Disposal
Rentry Solvent Blends	Envirosolve, Inc. 1840 Southside Boulevard Jacksonville, FL 32216 904-724-1990	Terpenes With Additives	Tailored To Meet Cleaning Needs	Waste Disposal Safety

CLEANER	SUPPLIER	TYPE	USE	POTENTIAL PROBLEM
Oxsol Solvents ^{TM} Family	OXYCHEM Occidental Tower 5005 LBJ Freeway Dallas, TX 75244 800-752-5151	Halogenated Aromatic Derivative Of Toulene	Formulated To Meet Specific Cleaning Needs	Varies With Formulation Check MSDS With Company
(1) Parts Prep (2) Micropure	International Specialty Products 1361 Alps Road Wayne, NJ 07470 800-622-4423	N-Methyl Pyrrolidone Plus Additives	(1) Parts (2) Circuit Board Cleaning	VOCs Drying Step Usually Required
(1) Ionox FC, HC, MC, LC (2) Aquanox SSA & 101	KYZEN Corporation 413 Harding Industrial Drive Nashville, TN 37211 615-831-0888 800-845-5524	(1) Alcohol & Surfactants & Sponifiers (2) Alcohol Alkaline, Water Blend	Electronics Precision Parts	Flammability Treatability Aquatic Toxicity.
3D SUPREME	3D Inc. 2053 Plaza Drive Benton Harbor, MI 49022-2211 616-925-5644 800-272-5326	Alkaline With Rust Inhibitor & Anti Foaming Agent Contains Glycol Ether	"Any Washable Surface "	Health (?) Treatment & Disposal.
Precision Clean	LPS Laboratories, Inc. 4647 Hugh Howell Road Tucker, GA 30085-5052 800-241-8334	Alkaline	Metals & Plastics	Safety

BATCH PARTS CLEANERS

NAME	COMPANY	TYPE	COMMENT
Safety Clean	Safety Kleen Corp. Box 1419 Elgin, IL 60120	Shop Parts Cleaners	Solvents and/or Petroleum Distillates
Action Bio-Clean	Action Products, Inc. 2401 W. 1st Street Tempe, AZ 85281 602-894-0100	Small Parts Washers	Aqueous
Jet Cleaner	Autop North America P. O. Box 150146 Nashville, TN 37215 615-255-7434	Automated Batch Cleaning Small Parts	Aqueous Process
Turbulator Cleaning Tanks	Atochem Turco Products, Inc. 7300 Bolsa Ave. Westminster, CA 92684-3600 714-890-3600	Agitated Aqueous Tank Cleaner.	Programmed Cleaning Cycles
P-30B "Spray Clean"	Peterson Machine Tool 5425 Antioch Drive Shawnee Mission, KS 66202 1-800-255-6308	High Pressure Spray Cabinet With Turntable	Engine & Shop Parts Cleaner
Hydro Pulse	GOFF Corp. P. O. Box 1607 Seminole, OK 74868 1-800-654-4633	Hot Water Parts Washer	No Cleaners

AQUEOUS EQUIPMENT, SUPPLIERS
SMALL TO MEDIUM

NAME	COMPANY	TYPE	COMMENT
Jet Washing	Better Engineering, Mfg. 7101 Belair Road Baltimore, MD 21206 1-800-638-3380	Cabinet With Turntable Fixed Jet Spray	Custom Design and Standard Units
Polychem Alternative 2000	U. S. Polychemical Corp. Route 45, P. O. Box 268 Spring Valley, NY 10997	Aqueous & Semi Aqueous Batch & Continuous Cleaners Including Ultrasonic	Family of Different Sized Units. Will Modify Existing Units
Immersion Washers	Bowden Industries 1004 Oster Drive, NW Huntsville, AL 35816 1-800-553-3637	Multiple unit Inline Automated Washer Conveyor or Monorail	Oil Skimmers, Filtration Multiple Rinse Components. Standard Units & Custom Design
Microdroplet Module Cleaning Process	Digital Equipment Corp. Maynard, MA 207-626-3939 Artisan (Vendor) 617-893-6800	Aqueous Inline Multiple Unit Precision Cleaner	Surface Mount Cleaning Aqueous With Saponifiers Uses Stoelting CBW224 Circuit Board Washer
MAGNUS Equipment	Man-Gill Chemical 23000 St. Clair Ave Cleveland, OH 44117 1-800-627-6422	Aqueous Metal Cleaning Batch & Inline	Replace Vapor Degreasing
Aqua-Quick, Model 600, Model 6300, Model 6307, etc.	Electronic Controls Design 4287-A SE International Way Milwaukee, OR 97222-8825 800-323-4548	Alcohol - Water (Batch) Closed System	Flash Point Precision & Electronics
ES TECH	Equipment Systems Technology P. O. Box 550 Findlay, OH 45840 419-424-4239	Rotary Drum with/wo Ultrasonics Conveyorized Wash/Rinse/Dry Batch or Continuous	Aqueous
5 Station Automated Cleaner	Advanced Deburring & Finishing Hwy. 70 East, P. O. Box 1004 Statesville, NC 28677 800-553-7060	Aqueous, Inline Multi Station Cleaning & Surface Preparation System or Cabinet Units	Drum or Power Spray Models
Jet Edge	Jet Edge Inc. 825 Rhode Island Ave. So. Minneapolis, MN 55426 612-545-1477 800-538-3343	High Pressure Water Jet	36,000 - 60,000 psi Cutting and Cleaning
Precision Cleaners	ATCOR 150 Great Oaks Blvd. San Jose, CA 95119-1367 408-629-6080 800-827-6080	Inline & Batch	Acqueous w/wo Ultrasonics
Advanced Vapor Degreasing	Petrofirm, Inc. 5400 First Coast Highway Fernandian Beach, FL 32034 904-261-8288	Closed System Vapor Degreasing With Perfluocarbon Rinse	Semi Acqqurous (Terpene) New Design or Retrofit.
Proceco Typhoon	Proceco, Inc. 1020 East 8th Street Jacksonville, FL 32206 904-355-2888	Heavy Duty Conveyor and Parts Washers	Multiple Processes

Appendix B
How To Calculate the Flow Rate of Rinse Water Required To Achieve a Specified Dilution Ratio

The three-stage counter-flow rinsing schematic in Figure B-l (which also appears in Chapter 7) is based on the following definitions and assumptions:

Definitions

a = concentration of chemical in Bath #3 (lb/gal)
b = concentration of chemical in Bath #2 (lb/gal)
c = concentration of chemical in Bath #l (lb/gal)
d = concentration of chemical in Process Bath (lb/gal)
x = flow rate of counter-flow rinse (gal/min)
y = flow rate of drag-in (gal/min)

Assumptions

- All baths are operating at their equilibrium concentrations.
- The flow rate of all counter-flow rinses (x) (gal/min) are the same.
- The flow rate of the drag-in (y) (gal/min) are the same for each stage.
- The concentration of contaminant in the makeup water to Bath #3 is zero.

Based on these definitions and assumptions, the flow rate and dilution ratio are calculated as follows:

Concentration of Solution in Bath #3

$$a(lb/gal) = \frac{y\,(gal/min) * b\,(lb/gal) + 0}{y\,(gal/min) + x\,(gal/min)}$$

Note: Because the incoming rinse water is clean, the concentration of process chemical in the water is zero.

or

$$a = \frac{yb}{y+x}$$

Therefore, the dilution ratio is:

$$\frac{b}{a} = \frac{y+x}{y}$$

or

$$\frac{b}{a} = 1 + \frac{x}{y} \qquad \text{(Eq. B-1)}$$

Concentration of Solution in Bath #2

$$b\,(lb/gal) = \frac{y\,(gal/\min) * c\,(lb/gal) + x\,(gal/\min) * a\,(lb/gal)}{y\,(gal/min) + x\,(gal/\min)}$$

$$b = \frac{yc + xa}{y+x}$$

The dilution ratio b/a is:

$$\frac{b}{a} = \frac{yc + xa}{a(y+x)}$$

But from Equation #1:

$$\frac{y+x}{y} = \frac{yc + xa}{a(y+x)}$$

$$a(y+x)(y+x) = y(yc + xa)$$

$$a(y^2 + 2xy + x^2) = y^2c + xya$$

$$ay^2 + 2xya + ax^2 = y^2c + xya$$

$$y^2c = ay^2 + xya + ax^2$$

The dilution ratio c/a is:

$$\frac{c}{a} = 1 + \left(\frac{x}{y}\right) + \left(\frac{x}{y}\right)^2 \qquad \text{(Eq. B-2)}$$

Concentration for Bath #3

$$c = \frac{yd + xb}{y+x}$$

Dividing both sides by a:

$$\frac{c}{a} = \frac{yd + xb}{a(y + x)}$$

Therefore, from Equation #2:

$$1 + \frac{x}{y} + \frac{x^2}{y^2} = \frac{yd + xb}{a(y + x)}$$

$$(y + x) + (y + x)\frac{x}{y} + (y + x)\frac{x^2}{y^2} = \frac{yd}{a} + \frac{xb}{a}$$

Substituting from Equation 1 for b/a:

$$y + x + x + \frac{x^2}{y} + \frac{x^2}{y} + \frac{x^3}{y^2} = y\frac{d}{a} + x\frac{(x + y)}{y}$$

Write the equation for the dilution ratio d/a:

$$y\frac{d}{a} = y + 2x + 2\frac{x^2}{y} + \frac{x^3}{y^2} - \frac{x^2}{y} - x$$

$$\frac{d}{a} = 1 + \frac{x}{y} + \frac{x^2}{y^2} + \frac{x^3}{y^3}$$

$$\frac{d}{a} = 1 + \left(\frac{x}{y}\right) + \left(\frac{x}{y}\right)^2 + \left(\frac{x}{y}\right)^3 \qquad \text{(Eq. B-3)}$$

The equation can be expanded for multiple counter-flow rinse stages,

$$\frac{K}{a} = 1 + \left(\frac{x}{y}\right) + \left(\frac{x}{y}\right)^2 + \ldots \left(\frac{x}{y}\right)^n$$

where:

K = concentration of the chemical in the process tank (lb/gal).
a = concentration of the chemical in the final rinse tank.
x = counter-flow rate (gal/min).
y = drag-in rate (gal/min).
n = number of rinse tanks.

For the simple case in which the drag-out (y) = 1 gal/min:

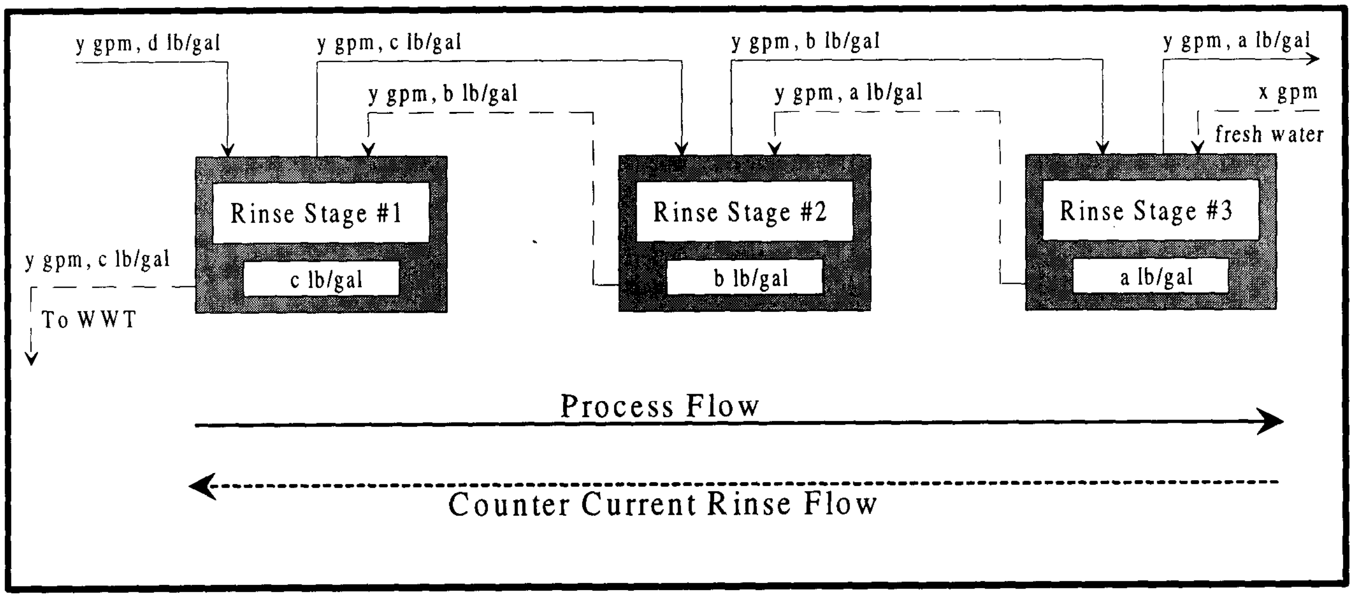
For Bath #3 b/a = 1 + x

For Bath #2 c/a = 1 + x + x^2

For Bath #3 d/a = 1 + x + x^2 + x^3

Note that the ratio x/y recurs in each term. Therefore, when the drag-in y = 2 gal/min, the counter-flow rate (x) must be twice as large; if y = 3, x will be three times as high compared with the counter-flow rate corresponding to a 1 gal/min drag-in rate.

Conversely, if the drag-in is well controlled and can be reduced to a fraction of 1 gal/min, the counter-flow rate (x) will be correspondingly lower.



a = concentration of chemical in Bath #3 (lb/gal)
b = concentration of chemical in Bath #2 (lb/gal)
c = concentration of chemical in Bath #1 (lb/gal)
d = concentration of chemical in process bath (lb/gal)
x = flow rate of counter-flow rinse (gal/min)
y = flow rate of drag-in (gal/min)

Figure B-1. Schematic of counter-flow rinsing.

Appendix C

Spreadsheet Model To Estimate Transfer Efficiency

Table C-l. Table of Assumptions

A	B	C	D
Surface area to be coated		3,500.00	ft^2/day
VOC of coating		3.5	Ibs/gal
Density of VOC portion		7.36	Ibs/gal
% Volume solids		52.45	%
Weight per gal (WPG)		9.8	Ibs/gal
% Weight solids (Calculated)		64.29	%
Cost of coating		$20.00	$/gal
Dry film thickness		1.5	mils
Transfer efficiency		30	%
Size of filters 20"x20"		OK	
No. of filters across		5	
No. of filters down		4	
Total no. of filters affected		20	
Holding capacity of filters		6	Ibs/filter
Percent of overspray going into filters		60	%
Percent efficiency of the filters		99	%
Percent PM_{10} in the overspray		99	%
Cost of filters		$5.00	$/filter
Number of filters which can be disposed of in 55-gal drum		40	filters/drum
Cost to dispose of 55-gal drum		$300.00	$/drum
Days of operation		251	days/yr
Labor required to replace filters		0.5	hours
Labor rate		$15.00	$/hour

Table C-2. Calculation of Costs (TE = 30%)

Total liquid gallons required	20.80	gals/day
Total liquid coating used	5,221.53	gals/year
Total solid coating used	2,738.47	solid gals/yr
Density of solid coating (Calculated)	12.01	Ibs/gal
Weight of solid coating used	32,897.84	Ibs solid/yr
Weight of total solid overspray	23,028.49	Ibs solid/yr
Weight of solid overspray in filters	13,817.09	Ibs solid/yr
Number of filters to be disposed of	2,302.85	filters/yr
Number of filter changes per year	115.14	filter changes/yr
Number of 55-gallon drums to be disposed of	57.57	drums/yr
Cost of hazardous waste disposal	$17,271.37	$/yr
Cost of filters	$11,514.24	$/yr
Labor hours to change filters	57.57	hours/yr
Labor cost to change filters	$863.57	$/yr
Number of wasted gallons	3,655.07	gals/yr
Cost of wasted paint	$73,101.44	$/yr
Summary		
Cost of waste + filters + labor	$29,649.18	$/yr
Cost of wasted paint	$73,101.44	$/yr
Total cost of waste	$102,750.62	$/yr

Table C-3. Calculation of Costs (TE = 45%)

Total liquid gallons required	13.87	gals/day
Total liquid coating used	3,481.02	gals/year
Total solid coating used	1,825.64	solid gals/yr
Density of solid coating (Calculated)	12.01	lbs/gal
Weight of solid coating used	21,931.90	lbs solid/yr
Weight of total solid overspray	12,062.54	lbs solid/yr
Weight of solid overspray in filters	7,237.53	lbs solid/yr
Number of filters to be disposed of	1,206.25	filters/yr
Number of filter changes per year	60.31	filter changes/yr
Number of 55-gallon drums to be disposed of	30.16	drums/yr
Cost of hazardous waste disposal	$9,046.91	$/yr
Cost of filters	$6,031.27	$/yr
Labor hours to change filters	30.16	hours/yr
Labor cost to change filters	$452.35	$/y
Number of wasted gallons	1,914.56	gals/yr
Cost of wasted paint	$38,291.23	$/yr
Summary		
Cost of waste + filters + labor	$15,530.52	$/yr
Cost of wasted paint	$38,291.23	$/yr
Total cost of waste	$53,821.76	$/yr

Table C-4. Formulas Used To Perform Calculations

A	B	C	D
Table of Assumptions			
Surface area to be coated		3,500.00	ft^2/day
VOC of coating		3.5	lbs/gal
Density of VOC portion		7.36	lbs/gal
% Volume solids		=(I-C5/C6))*100	%
Weight per gal (WPG)		9.8	lbs/gal
% Weight solids (Calculated)		64.29	%
Cost of coating		$20	$/gal
Dry film thickness		1.5	mils
Transfer efficiency		30	%
Size of filters 20” x 20”		OK	
No. of filters across		5	
No. of filters down		4	
Total no. of filters affected		=C14*C15	
Holding capacity of filters		6	lbs/filter
Percent of overspray going into filters		60	%
Percent efficiency of the filters		**99**	%
Percent PM_{10} in the overspray		**99**	%
Cost of filters		**5**	$/filter
Number of filters which can be disposed of in 55-gal drum		40	filters/drum
Cost to dispose of 55-gal drum		300	$/drum
Days of operation		251	days/yr
Labor required to replace filters		0.5	hours
Labor rate		15	$/hour
Calculation of Costs (TE = 30%)			
Total liquid gallons required		= C4*c11*100*100/(1604*C7*C12)	gals/day
Total liquid coating used		= C3O*C24	gals/year
Total solid coating used		= C31*C7/100	solid gals/yr
Density of solid coating (Calculated)		= C9*C8/C7	lbs/gal
Weight of solid coating used		= C32*C33	lbs solid/yr
Weight of total solid overspray		= C34*(1-Cl2/l00)	lbs solid/yr
Weight of solid overspray in filters		= C35*C18/100	lbs solid/yr
Number of filters to be disposed of		= C36/C17	filters/yr
Number of filter changes per year		= C37/C16	filter changes/yr
Number of 55-gallon drums to be disposed of		= C37/C22	drums/yr
Cost of hazardous waste disposal		= C39*C23	$/yr
Cost of filters		= C37*C21	$/yr
Labor hours to change filters		= C38*C25	hours/yr
Labor cost to change filters		= C42*C26	$/yr
Number of wasted gallons		= C31*(1-C12/100)	gals/yr
Cost of wasted paint		= C44*ClO	$/yr
Summary			
Cost of waste + filters + labor		= C40+C41+C43	$/yr
Cost of wasted paint		= C45	
Total cost of waste		= SUM (C48:C49)	$/yr

Index

Inclusive references in bold type indicate a general discussion of the entry topic.

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