

a Guide to High-performance

POWDER COATING

Bob Utech



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Dearborn, Michigan

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The Society of Manufacturing Engineers is the world's leading professional society supporting manufacturing education. Through its member programs, publications, expositions, and professional development resources, SME promotes an increased awareness of manufacturing engineering and helps keep manufacturing professionals up to date on leading trends and technologies. Headquartered in Michigan, SME influences more than half a million manufacturing engineers and executives annually. The Society has members in 70 countries and is supported by a network of hundreds of chapters worldwide. Visit SME at www.sme.org.

About AFP/SME

The Association for Finishing Processes of SME (AFP/SME) covers all technology, process, and management aspects of cleaning and coating metal and plastic parts used in manufactured products. Members are in the big automotive and aerospace plants and Tier One supplier facilities, as well as in companies manufacturing everything from office furniture to toys. AFP/SME members include process engineers who implement automated powder coating lines; product engineers who specify liquid, waterborne, or electrostatic finishes; managers of processes such as deburring, buffing, polishing, or chemical pretreatment; and supervisors of post-production air and water treatment, emissions control, recycling, and liquid waste and sludge disposal systems. AFP/SME sponsors national conferences and regional clinics on topics such as planning painting system layouts, troubleshooting coating durability problems and defects, evaluating advanced curing technologies, decorating plastics, implementing robotic finishing lines, and analyzing EPA regulations. To find out more, visit AFP/SME at www.sme.org/afp.

Dedication

I dedicate this book to my wife Patty, and to our children Christy, Brandon, Candi, Dani, and Cory. Patty knew the right words of encouragement when I was down, gave me advice when I needed it, and offered me emotional support when I needed her presence.

Over the years, I've seen the powder-coating industry grow. I like to think that I, too, have grown as an individual because of my personal and professional involvement with the following individuals.

I would like to thank Jim Docken and Bruce Allen for their contributions to my professional education in the pretreatment and powder-coating fields. These colleagues presented ideas and concepts to me that I would not have learned about the industry on my own. Both individuals contributed not only to my education, but also to the success of the entire finishing industry. They represent the quality I value in my suppliers, as well as in my friends. I thank them for sharing their considerable knowledge and talent, and for their continued support of the powder-coating arts.

Some people succeed by what they know, some by what they do, and a few by who they are. My mentor, Glen Swanson, succeeded for all three of these reasons. Through many years, Glen has been involved positively in many issues that those in the industry face. Glen has always been determined to do the best for all concerned—from students, to vendors, to users, to people in government. He possesses the personal skills that make things happen. He is the type of person anyone would want for a friend and colleague, and I am privileged to have had the opportunity to be both. Glen's professional stature is recognized across the industry.

I also want to thank Don Lawson, who has always exemplified quality workmanship. Don was fond of saying to me: “If it’s worth doing, it’s worth doing well.” I now embrace that value and hope you will as well.

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Preface

Many successful manufacturers have dedicated their educational efforts toward helping people be productive and efficient in the powder coating industry. This book was written to be one of the tools used in that educational process. It offers in-depth information about system design and layout, equipment features and benefits, system efficiency, operating costs, maintenance, and coating comparison. It also includes information about process control, and the variables leading to efficiency, quality, and consistent operation of finishing processes.

Material covered includes the basic processes and equipment used in electrostatic spray operations. Other topics include application equipment, powder materials, booths, reclaim systems, washers, ovens, operating costs, system efficiency, continuous improvement, and other areas. Powder coating's advantages and its formulations are discussed. Information on equipment design and the application process is also included.

With powder coating, proper application and pretreatment procedures must be used for the highest cosmetic and longevity potential. Pretreatment, a commonly abused process, is discussed at length. For instance, many times pretreatment is left unsupervised and improperly maintained, and many companies do not titrate on a schedule, or at all. At times, workers will add chemicals by merely looking at the parts to determine if chemicals are needed. This is an improper practice and it is a sure bet that customer service will be contacted later by dissatisfied customers. The pretreatment system is—and should be regarded as—one of the most important steps in the powder paint application process.

Acknowledgments

This book gives me the opportunity to address not only newcomers to the powder coating industry, but also my peers who have worked for many years in the field.

Life is full of experiences: some fulfilling, some fraught with mistakes. This book is based on my experiences, both personal and professional. My gratitude goes out to the colleagues who helped me limit my mistakes by giving me support. To my peers and those that have helped in the authoring of this book, I offer my sincere thanks for their assistance.

Thanks to Steve Keifer, who served as a reviewer for the material in this book, and to James Docker, who provided input at the book's early stages. I also thank David Hagood for contributing the UV curing material in Chapter 18.

Thanks also to the staff at the Society of Manufacturing Engineers, Reference Publications Department, whose professional efforts in organization, editorial development, and book production helped bring this book to the industry.

I offer this closing thought: from time to time, almost any profession and the technology associated with it come under fire to make rapid changes. Just like steel, people under fire have been known to form and harden. However, they are parts of a process that can achieve greatness. We, as the developers and users of powder-coating processes, periodically come under fire to make rapid changes. Hopefully, we, as a professional group, will continue to lead the way in this industry.

The book shows that powder coating is one of the fastest growing mediums for applying coating. It examines industry costs, performance, and environmental effects. Technical advancements made in powder and equipment are explained to help companies maintain a competitive edge for years to come.



Powder Coating: An Overview

Powder coating involves applying a finely ground resin (powder) to a substrate and subjecting this powder to heat. During the heating process, the powder melts and creates a uniform, continuous coating. Powder coatings provide excellent corrosion, impact, and abrasion resistance, as well as gloss retention. Manufacturers employ powder coating processes in a wide variety of applications as they are versatile and present savings in labor, materials, and energy costs, and because powder coats are durable.

Powder coating dates to the 1950s when powders were flame-sprayed on metallic surfaces to protect them from corrosion and abrasion. As the process evolved, most powder-coating applications involved lowering a heated part (sometimes referred to as a “ware” or a “substrate”) into a bed of fluidized powder. However, this process resulted in inconsistent film thickness. Electrostatic spray equipment, introduced in the early 1960s, enabled powder coatings to be applied to cold substrates, resulting in more uniform, thinner surface application and thus, savings in raw materials.

Today, powder-coating processes are employed in many production settings involving protective finishes. Powder formulations can be created to deliver cosmetic, protective, and longevity characteristics, and to achieve maximum hardness, chemical resistance, and gloss retention. Powder coatings may be applied to hot and

cold substrates and when corrosives or high pressure are used. Furthermore, the simplicity of the process allows automation.

Automobile manufacturers, for example, use powder coatings to protect under-hood parts from extremes in temperature, atmosphere, and pressure. The industry also discovered that powder coatings improve the quality of finishes on wheels, bumpers, mirror frames, oil filters, battery trays, and coil springs. Recently, some automakers have been using powder coatings not only as primers for topcoats, but also as the topcoats themselves, with great success. This is a revolutionary step. Some appliance manufacturers replace the energy-intensive process of applying a porcelain finish on washing machine lids with specially formulated scratch-resistant powder coatings. Major appliance parts, such as range housings, freezer cabinets, dryer drums, and microwave oven cavities and outer shells, are now powder coated. Outdoor lawn furniture, garden tractors, wheelbarrows, and shovels also benefit from powder coating. Figure 1-1 shows some examples of powder-coated items. Industry researchers continue to investigate and develop new powder coating materials, such as acrylics, for smoothness and gloss, low-cure-temperature coatings, high-temperature coatings, and wood-powder coatings.

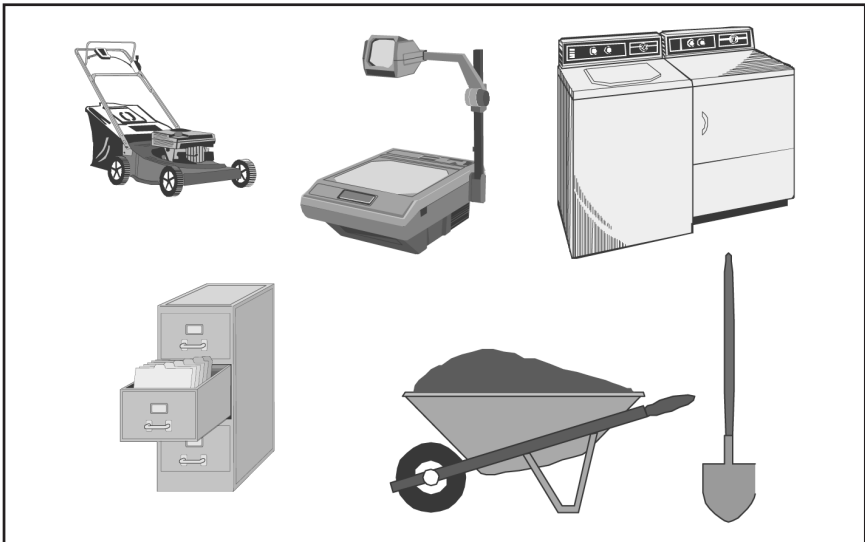


Figure 1-1. Examples of powder-coated items.

The automotive and appliance industries are the largest markets for powder coating in North America. In 1999, the two industries accounted for 32% of total usage. A report from the Association for Finishing Processes at SME (AFP/SME) also indicates that architectural and lawn and garden markets make up 10.5% of usage and a collection of other industries consume the remaining 57% (AFP/SME 1999).

ECONOMIC BENEFITS

Although equipment and materials costs are similar in powder-coating and liquid-coating processes, powder-coating processes provide a number of advantages over other surface-coating methods. These include:

- fewer rejects;
- less floor space required;
- less material waste;
- lower energy costs;
- lower training and labor costs;
- lower waste-disposal costs;
- more efficient cleaning operations; and
- more uniform finishes.

Powder-coating materials are shipped ready to use and are easy to apply, thus labor costs associated with training, setup, and processing are low when compared with liquid-coating processes. Powder coating's overall utilization efficiency is high (90–95%), compared with many liquid spray coating methods, so the powder process usually coats more square feet per pound of purchased coating. Furthermore, liquid coatings usually require thinning before application, leading to additional material and labor costs. This is not the case with powder coating. Liquid paint requires flash-off time before surfaces can be recoated; powder coating does not, meaning that racks can be spaced closer together and thus more parts per hour can be processed.

Powder coatings generally are applied electrostatically. As the powder passes through a charged corona field, it receives a positive or negative charge. Most of the powder attaches to the closest

ground, which is the part, and the remaining powder falls into a collection hopper where it can then be re-sieved and reused. This aspect of the process results in an enormous cost savings when compared with liquid-coating systems because it increases first-pass efficiency and reduces material waste. (Material utilization is 95%.)

Powder-coating processes result in fewer rejects than liquid-coating processes. Since powder coating is a dry process, air- and water-associated problems—such as sags, runs, and contamination—are almost eliminated. Blowing off the surface with an air hose and reapplying the powder can easily repair coating rejects in the booth or application area.

Cleaning powder-coating equipment is easily accomplished by using air to blow back residual powder left inside a hose or hopper. To clean liquid systems, solvent or water must be run through the lines and equipment, and these toxic liquids must be disposed of. Because of the transfer efficiency of powder-coating processes, less material requires disposal than in liquid-coating systems. Furthermore, properly cured waste powder is not considered a hazardous waste, so it may be landfilled.

Generally, powder-coating systems allow more precise application of a topcoat to a substrate surface than liquid-coating systems. Powder-coated parts are cured evenly in an oven, and the result is an even finish without the spray spots characteristic of liquid coating.

ENVIRONMENTAL BENEFITS

Powder coating has gained widespread attention in the finishing industry as an effective means of reducing air pollution. Powder coating performance characteristics equal those of liquid coating, but the environmental benefits of powder coating make it far superior.

In the past, manufacturers chose conventional methods of surface finishing because volatile organic compounds (VOCs) were not tightly regulated. However, federal, state, and local environmental regulatory agencies have mandated that every industry reduce the volatile organic chemicals being emitted to the atmo-

sphere. Consequently, engineers attempting to increase production and trim costs must include environmental regulation compliance in their plans. Companies must be concerned not only with throughput, inventory, and operating expenses as measures of the company's growth and consistency; they also must be concerned with the impact of their activities on the health of workers, the community, and the environment. Many manufacturing and production companies have realized large savings in this area by using powder-coating processes. With environmental standards increasingly being tightened, many more companies will be looking to powder coating as a cost-effective and less-toxic alternative to conventional surface-coating processes.

Conventional coating systems rely on volatile organic compounds (solvents) or water to convey the resinous binder over a surface. Powder-coating systems, which are dry and solvent-free, do not require a solvent to provide coverage and flow. Thus, few, if any, toxic compounds are released into the air or water during processing. No solvents are required for mixing, cleaning, or maintaining powder-coating systems and thus safety rooms for storing hazardous materials are unnecessary. Because solvent emissions are almost eliminated, venting to the outside is unnecessary in a properly designed powder-coating system. The low volume of toxic, gaseous, or explosive fumes emitted during the curing of powders can also reduce venting requirements in the curing oven. Additionally, most powder-coating materials are free of heavy metals, and no special permits or trucks are required to transport materials (except when transporting very low temperature or very fast cure materials, which may need refrigeration). A high percentage of powder overspray can be recovered and reused; the rest can be cured and sent to the landfill as a block.

ENVIRONMENTAL AND SAFETY REGULATIONS

The cost of compliance with environmental and safety regulations has consumed a sizable portion of the finishing industry's new technology investment over the past 15 years. Companies are responsible for complying with local, state, and federal environmental and safety regulations. In the United States, the Environ-

mental Protection Agency (EPA) and the 1977 Clean Air Act (and amendments) established environmental quality standards, including guidelines for toxic-waste disposal. One goal of the EPA's Environmental Technology Verification (ETV) Coatings and Coating Equipment Program is to reduce emissions by encouraging the application of powder coatings and ultraviolet-curable liquid coatings. Since the inception of this program, ultraviolet-curable liquid coatings gained popularity with coaters. However, powder coatings for metal substrates are experiencing a current 6–8% annual growth rate.

The Williams-Steiger Occupational Safety and Health Act of 1970 created the Occupational Safety and Health Administration (OSHA) in the U.S. Department of Labor. OSHA establishes guidelines and supervises the creation and maintenance of a clean, healthy, and safe workplace environment for workers. It mandates such items as respiratory protection, proper equipment guards, and color codes for hazardous materials.

State and local governments also have environmental and safety regulatory agencies. California, for example, has been a leader in promoting a safe environment. The California Air Resources Board (CARB) is charged with promoting and protecting public health, welfare, and ecological resources through the effective and efficient reduction of air pollutants, while recognizing and considering the effects on the economy of the state. It monitors industry emissions of volatile organic compounds to permit more accurate air-quality modeling for planning and analysis. CARB also investigates whether additional flexibility can be built into local regulations based on the reactivity of ingredients.

Material Safety Data Sheets (MSDS) may be required in some states. MSDSs are designed to meet the requirements of OSHA and are prepared by the product manufacturers. These sheets include information about product ingredients, proper handling, as well as fire, safety, and medical precautions. Figure 1-2 presents a sample MSDS. Many samples of these sheets are available on the Internet.

Because most finishing operations today comply with air emissions regulations, many formulators and equipment suppliers are beginning to focus their investment strategies on:

TRIMITE POWDERS—POWDER COATING, E05068-PA5002-2
MATERIAL SAFETY DATA SHEET

NSN: 803000N060549

Manufacturer's CAGE: TRMTE

Part No. Indicator: A

Part Number/Trade Name: POWDER COATING, E05068/PA5002/2

General Information

Company's Name: TRIMITE POWDERS, INC.

Company's Street: 5680 NORTH BLACKSTONE RD.

Company's P.O. Box: 2785

Company's City: SPARTANBURG

Company's State: SC

Company's Country: US

Company's Zip Code: 29304

Company's Emergency Phone Number: 803-574-7000

Company's Info Phone Number: 803-574-7000

Record No. for Safety Entry: 001

Tot Safety Entries This Stk#: 001

Status: SMJ

Date MSDS Prepared: 11 APR 94

Safety Data Review Date: 21 JUN 95

MSDS Serial Number: BXVKM

Ingredients/Identity Information

Proprietary: NO

Ingredient: WALLASTONITE; (CALCIUM METASILICATE)

Ingredient Sequence Number: 01

Percent: 12.95

NIOSH (RTECS) Number: ZC7950000

CAS Number: 13983-17-0

OSHA PEL: 15 MG/M3 (MFR)

ACGIH TLV: 10 MG/M3 (MFR)

Proprietary: NO

Ingredient: SILICA, AMORPHOUS, DIATOMACEOUS EARTH; (SILICA-AMORPHOUS)

Ingredient Sequence Number: 02

Percent: 1.59

NIOSH (RTECS) Number: VV7311000

CAS Number: 61790-53-2

OSHA PEL: 20 MPPCF

ACGIH TLV: 10 MG/M3 TDUST

Proprietary: NO

Ingredient: TITANIUM OXIDE; (TITANIUM DIOXIDE)

Ingredient Sequence Number: 03

Percent: 11.4

NIOSH (RTECS) Number: XR2275000

CAS Number: 13463-67-7

OSHA PEL: 15 MG/M3 TDUST

ACGIH TLV: 10 MG/M3 TDUST

Figure 1-2. Sample Material Safety Data Sheet.

Physical/Chemical Characteristics

Appearance and Odor: FINELY DIVIDED POWDER; SLIGHT, IF ANY ODOR.

Melting Point: > 194° F, > 90° C

Specific Gravity: > 1.2

Decomposition Temperature: < 527° F, < 275° C

Solubility in Water: NEGLIGIBLE

Percent Volatiles by Volume: < 1

Fire and Explosion Hazard Data

Flash Point: NOT APPLICABLE

Lower Explosive Limit: 30-70 GM/CM

Extinguishing Media: CARBON DIOXIDE, DRY CHEMICAL, FOAM AND/OR WATER.

Special Fire Fighting Procedure: USE NIOSH/MSHA APPROVED SCBA AND FULL PROTECTIVE EQUIPMENT (FP N).

Unusual Fire and Explosive Hazards: DECOMPOSES W/OUT FLASHING. REFER TO NFPA 1977 EDITION OF #33, CHAPTER 13—ORGANIC SOLIDS DUST WHEN SUSPENDED IN AIR. CORRECT RATIO IS FLAMMABLE IF IGNITED. (SUPDAT)

Reactivity Data

Stability: YES

Conditions to Avoid (Stability): NONE KNOWN.

Materials to Avoid: STRONG OXIDIZERS, ACIDS.

Hazardous Decomposable Products: CARBON MONOXIDE, CARBON DIOXIDE, NITROGEN OXIDES, METAL OXIDES.

Hazardous Poly Occur: NO

Conditions to Avoid (Poly): NOT RELEVANT

Health Hazard Data

LD50-LC50 Mixture: NONE SPECIFIED BY MANUFACTURER.

Route of Entry—Inhalation: YES

Route of Entry—Skin: NO

Route of Entry—Ingestion: NO

Health Hazards Acute and Chronic: ACUTE: INGESTION: HARMFUL IF SWALLOWED. INHALATION: MAY CAUSE RESPIRATORY IRRITATION. EYE CONTACT: MAY CAUSE IRRITATION. SKIN: MAY CAUSE IRRITATION AND/OR SENSITIZATION. CHRONIC: NONE CURRENTLY KNOWN.

Carcinogenicity—NTP: NO

Carcinogenicity—IARC: NO

Carcinogenicity—OSHA: NO

Explanation Carcinogenicity: NOT RELEVANT

Signs/Symptoms of Overexposure: SEE HEALTH HAZARDS.

Medical Conditions Aggravated by Exposure: RESPIRATORY DISEASE.

Emergency/First Aid Procedure: INGESTION: IF SWALLOWED GET MEDICAL ATTENTION. INHALATION: REMOVE TO FRESH AIR. GET MEDICAL ATTENTION. EYE: FLUSH W/WATER FOR AT LEAST 15 MINUTES. GET MEDICAL ATTENTION. SKIN: REMOVE CONTAMINATED CLOTHING. WASH W/SOAP AND WATER. IF IRRITATION PERSISTS, GET MEDICAL ATTENTION.

Precautions for Safe Handling and Use

Steps if Material Released/Spill: SWEEP OR VACUUM AND PLACE IN CLOSABLE CONTAINER FOR DISPOSAL. WEAR PROTECTIVE EQUIPMENT AS SPECIFIED.

Neutralizing Agent: NONE SPECIFIED BY MANUFACTURER.

Waste Disposal Method: DISPOSE I/AW FEDERAL, STATE AND LOCAL REGULATIONS.

Figure 1-2. (continued)

Precautions—Handling/Storing: AVOID FREE-FALL OF POWDER IN EXCESS OF A FEW INCHES. I/A/W GOOD INDUSTRIAL PRACTICE, HANDLE W/CARE AND AVOID PERSONAL CONTACT.

Other Precautions: USE ONLY W/ADEQUATE VENTILATION. AVOID BREATHING DUST OR VAPORS. FOR INDUSTRIAL USE ONLY.

Control Measures

Respiratory Protection: USE NIOSH/MSHA APPROVED DUST MASK.

Ventilation: VENT EQUIPMENT SHOULD BE EXPLOSIVE PROOF AND KEEP HAZARDOUS INGREDIENTS LISTED BELOW LOWEST EXPOSURE LIMIT STATED. FUMES EMITTED WHEN (SUPP DATA)

Protective Gloves: IMPERVIOUS GLOVES (FP N).

Eye Protection: ANSI APPROVED CHEMICAL WORKER GOGGLES (FP N).

Other Protective Equipment: EYE WASH FOUNTAIN AND DELUGE SHOWER THAT MEET ANSI DESIGN CRITERIA (FP N). APPROPRIATE INDUSTRIAL WORK CLOTHES.

Work Hygienic Practices: WASH FACE AND HANDS THOROUGHLY AFTER HANDLING AND BEFORE EATING, DRINKING, OR USING TOBACCO PRODUCTS.

Supplemental Safety and Health Data: EXPLOSIVE HAZARD: DUST CONTROL AND GOOD HOUSE-KEEPING IS REQUIRED. VENT:CURING PRODUCT MUST BE VENTED.

Transportation Data

Disposal Data

Label Data

Label Required: YES

Technical Review Date: 21JUN95

Label Date: 12JUN95

Label Status: G

Common Name: POWDER COATING, E05068/PA5002/2

Chronic Hazard: NO

Signal Word: WARNING!

Acute Health Hazard—Moderate: X

Contact Hazard—Moderate: X

Fire Hazard—None: X

Reactivity Hazard—None: X

Special Hazard Precautions: ACUTE: INGESTION: HARMFUL IF SWALLOWED.

INHALATION: MAY CAUSE RESPIRATORY IRRITATION. EYE CONTACT: MAY CAUSE IRRITATION. SKIN: MAY CAUSE IRRITATION AND/OR SENSITIZATION.

CHRONIC: NONE LISTED BY MANUFACTURER.

Protect Eye: Y

Protect Skin: Y

Protect Respiratory: Y

Label Name: TRIMITE POWDERS, INC.

Label Street: 5680 NORTH BLACKSTONE RD.

Label P.O. Box: 2785

Label City: SPARTANBURG

Label State: SC

Label Zip Code: 29304

Label Country: US

Label Emergency Number: 803-574-7000

Figure 1-2. (continued)

- cutting product costs,
- boosting transfer efficiency, and
- improving coatings quality.

Government regulations resulted in growth of the custom coating industry. Small- and medium-size manufacturers who do not possess the staff or equipment to know the latest regulations, outsource their finishing work to custom coaters who possess the required equipment and expertise to complete the needed paperwork. (As these custom coaters become a growing source of manufacturing engineering information, they will likely become part of concurrent engineering teams.)

Another change in the relationship between users and suppliers is more reliance on suppliers to manage the users' chemicals. In such chemical management programs, the supplier takes responsibility for managing either a portion or all of the operation's chemicals and presenting the user with a monthly invoice. Users often see substantial cost savings through better inventory control, less invoicing and servicing costs, optimum product usage, product selections based on the entire manufacturing process instead of one operation, and greater manpower utilization. Moreover, the proactive service from having the chemical supplier on the continuous improvement team can help the user meet his or her quality goals and comply with laws and regulations (AFP/SME 1999).

BECOMING INFORMED AND STAYING THAT WAY (AFP/SME 2000) _____

Unfortunately, getting formal training in industrial finishing technology is difficult. Despite a great deal of activity in the industry, the subject continues to be a very difficult curriculum to mark at community colleges. When one technical college in northwestern Ohio instituted such a program for an Associate Degree in Industrial Finishing Technology about three years ago, continually low enrollment led to its elimination. Currently, on-the-job training is how the skills are learned. Companies typically conduct in-house training, have their employees attend training seminars, or do a combination of both.

Vendors often assume the responsibility for training users and keeping them up to date. Because of continued interest in ultraviolet-curable liquid coatings, for example, one industrial finishing application equipment manufacturer has invested in a customer service laboratory dedicated exclusively to demonstrating the application of ultraviolet-curable liquid coatings. An in-house training facility there also offers customers courses about liquid coating technology.

Other vendors and research groups are using the Internet to give users the latest technical help. The number of web sites devoted to solving productivity, environmental, and safety problems in the finishing and coating industries is growing, often thanks to EPA subsidies. Users, therefore, can find a multitude of on-line services supporting their day-to-day activities.

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Association for Finishing Processes of SME (AFP/SME). 2000. *2000 Report on Trends in the Finishing Industry*. Dearborn, MI: Association for Finishing Processes of the Society of Manufacturing Engineers.

2

Powder-coating Materials and Their Performance Properties

TYPES OF POWDERS

Powder coatings are formulated from plastic resins, fillers, pigments, binders, cross-linkers, and flow agents (see Figure 2-1). Powder-coating manufacturers achieve specific formulations by varying ingredients and their proportions, which determine the powder's and final coating's properties once the coating is applied to the substrate. Powders are made in batches, with each batch assigned a unique number based on its formulation. After the

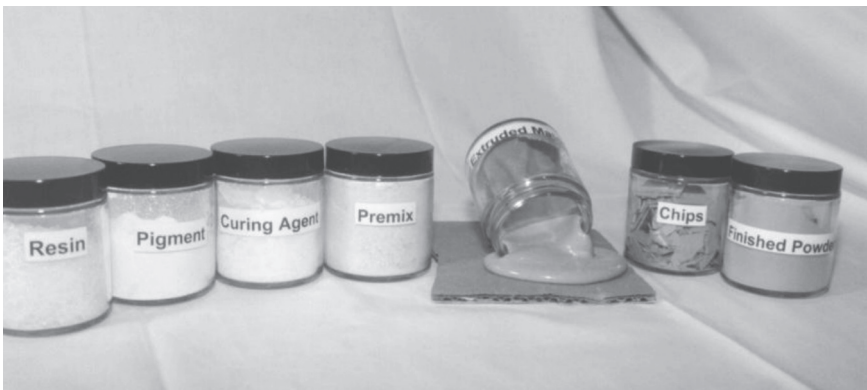


Figure 2-1. Powder coating components.

ingredients are carefully weighed and dry mixed, the mixture is uniformly fed into an extruder and heated, producing a homogeneous composite. The heat required for extrusion is not high enough to induce chemical reactions among the ingredients, so curing does not occur during the process. As the mixture takes on the consistency of taffy, it is fed through a chilled roller and flattened. The flattened material is then fed onto a wide belt for cooling, and a shaker at the end of the belt breaks up the hardened material into potato chip-sized pieces. The material is ground to size, sieved, and boxed for storage or shipment.

Powder-coating resins are dry, plastic resins. Unlike the liquid materials in water-reducible, radiation-cured, and electrocoat technologies, the resins in powder coating are 100% film-forming materials. They are solid at ambient temperature and capable of melting quickly to low viscosities, providing a continuous film coating. Once the powder-coated substrate enters the curing stage, the powder melts and flows to fully encompass the part. This continuous coating gives powder-coated surfaces superior durability and performance properties and an appealing appearance.

When powder resins were first used for surface finishing, they were limited in their ability to meet the finishing industry's diverse needs. However, technological developments in the industry greatly expanded powder resin's capabilities. Powder-coating processes better meet industry demands, often exceeding the capabilities of solvent-based and water-based surface-finishing processes.

Many powder companies provide stock powder coatings, but end users typically request customized powders formulated to meet a specific application's needs. Often, customizing involves matching the end user's stocked colors and performance requirements.

The two major powder coating types are *thermoplastic powders* and *thermosetting powders*.

Thermoplastic Powders

A *thermosplastic powder coating* is one that melts and flows with the application of heat, but maintains the same chemical composition when it solidifies on cooling. Thermoplastic powder

coatings are based on thermoplastic resins of high molecular weight. These tough and resistant resins tend to be difficult and also expensive to grind into the fine particles necessary for the fusion of thin paint-like film thickness (Wick and Veilleux 1985).

Thermoplastics powders do not chemically react during application or curing, nor do they cross-link. Therefore, they can be reheated, enabling an entire coating to be reflowed—a useful property allowing minor flaws to be touched-up. Thermoplastic powder coatings are used primarily for functional protective purposes, because they are difficult and expensive to finely grind, and they are not suitable for spraying and thin film applications. They are generally applied using fluidized-bed equipment to achieve a coating thickness of 10–30 mil (0.25–0.80 mm). Desired thickness can be achieved by reheating the fluidized powder and redipping the part.

Fluidized-bed coating is a method for applying thermosetting or thermoplastic materials in the form of fine powders to preheated metal parts. The powders are placed in the upper chamber of a dip tank. Pressurized air flows through a diffuser plate into a powder chamber, causing the powder to become suspended (fluidized) in the airstream. In this state, the air-powder mixture resembles a boiling liquid. The part to be coated is heated to a temperature above the powder's melting point and then immersed in the air-powder mixture (see Figure 2-2). The powder particles that contact the hot surface begin to fuse and form a film on the surface. Uniform distribution of particles over the surface is enhanced by vibrating the part while it is in the powder chamber.

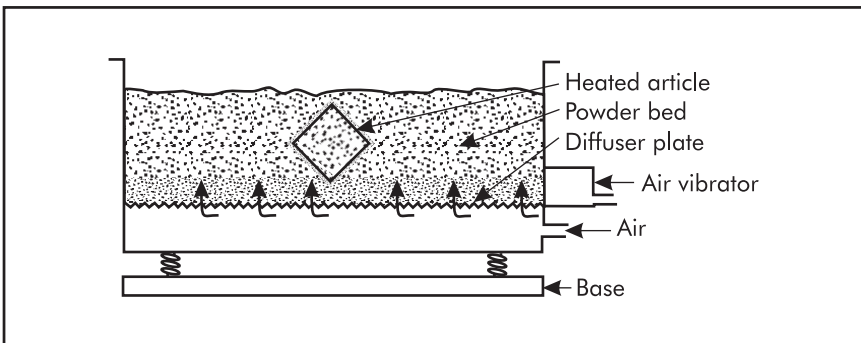


Figure 2-2. Schematic diagram of a fluidized powder bed (Wick and Veilleux 1985).

After the part is removed from the chamber, it is generally reheated to achieve good fusion and film properties; in the case of thermosetting powders, reheating is performed to cure the coating (Wick and Veilleux 1985).

A variety of thermoplastic powders are available:

- *Polyvinyl chloride (PVC) powders* are designed to provide good weathering properties and they possess the ability to withstand bending. Most PVC powders are applied through a fluid-bed process and are flowed in a convection oven. PVC coatings usually require a suitable primer to be first applied to the substrate. PVC powder coatings can be tricky to apply, but the process provides excellent film-building properties. Once cured, PVC leaves a soft, protective surface.
- *Polyamide powders* offer a tough coating with excellent abrasion, wear, and impact resistance, as well as a low coefficient of friction when applied over a suitable primer. Since polyamid has a unique combination of low coefficient of friction and good lubricity, it is ideal for applications with sliding and rotating bearings, such as automotive spline shafts and relay plungers.
- *Polyethylene powders* were the first thermoplastic powder coatings offered in the industry. They provide excellent chemical resistance and toughness with outstanding electrical insulation properties. They have good release properties, allowing viscous, sticky materials to be easily cleaned from their surfaces.
- *Polypropylene*, because it is inert, shows little tendency to adhere to metal or other substrates. Therefore, natural polypropylene used as a surface coating must be chemically modified for it to adhere to the substrate.

Thermosetting Powders

Most powder-coating materials are thermosetting powders. The greatest technological advances in powder coatings are being made in this area (at this writing). Thermosetting powders are composed of solid resins higher in molecular weight than

resins found in liquid coatings and lower in molecular weight than those found in thermoplastics.

The solid resins melt and flow chemically, and cross-link within themselves or with other reactive components forming a higher molecular-weight reaction product. The coating film formed by this reaction is heat stable and will not soften back to a liquid on further exposure to heat (Wick and Veilleux 1985). At these higher temperatures, a coating emerges with different chemical properties than before heating.

The types of resins commonly used in thermosetting powder include:

- several types of epoxies,
- hydroxyl and carboxyl types of polyesters,
- several types of acrylics, and
- several types of silicones.

They require lower temperatures for curing than thermoplastic resins. Powder manufacturers can add components to the powder-coating material to control when the reaction occurs during the curing phase. Once the powder has fully cross-linked (cured), it cannot be reflowed. Subjecting the part to proper heating and letting the powder continually flow until all cross-linking occurs is crucial to the part's cosmetic appearance. This is particularly true of textures, veins, and other specialty powders.

End users of powder coats must clearly communicate to powder manufacturers/suppliers the precise performance and appearance properties required for a specific application, such as corrosion and impact resistance, cure cycle, gloss, color, and texture. The powder manufacturer can then supply a stock or custom formulation designed to meet the end user's needs.

How finely a resin is ground also may affect its flow when heated. Resin-based powders can be ground to 0.0004–0.0040 in. (10–100 μm). Due to the rheological characteristics of these resins, they can produce thin, paint-like surface coatings in the 1–3 mil (0.025–0.076 mm) range with properties comparable to—and sometimes superior to—coatings produced by liquid-coating systems. Figures 2-3 and 2-4 show typical devices used to apply thermosetting powders.



Figure 2-3. Typical powder-coating spray gun and powders.

The most significant breakthrough in thermosetting technology has been the development of engineered resin systems designed to meet the diverse and specific needs of the metal-finishing industry. Although epoxy resins were used almost exclusively during the early years of thermoset coatings and are still widely used today, polyester and acrylic resins are gaining in popularity, especially in the appliance and automotive industries. These powders can provide excellent resistance to corrosion, heat, impact, and abrasion. Color selection is almost unlimited, with high and low gloss and clear finishes available. Texture selections range from smooth surfaces to a wrinkled or matte finish. Film thickness is varied to suit the specific application requirement.

Thermosetting powder coats find a wide range of applications because they are decorative and durable. To restate, the most common types of thermosetting powders are epoxies, epoxy-polyester hybrids, urethane polyesters, polyester-triglycidyl isocyanurate (TGIC), and acrylics. Table 2-1 summarizes the properties of these common thermosetting powder coatings.

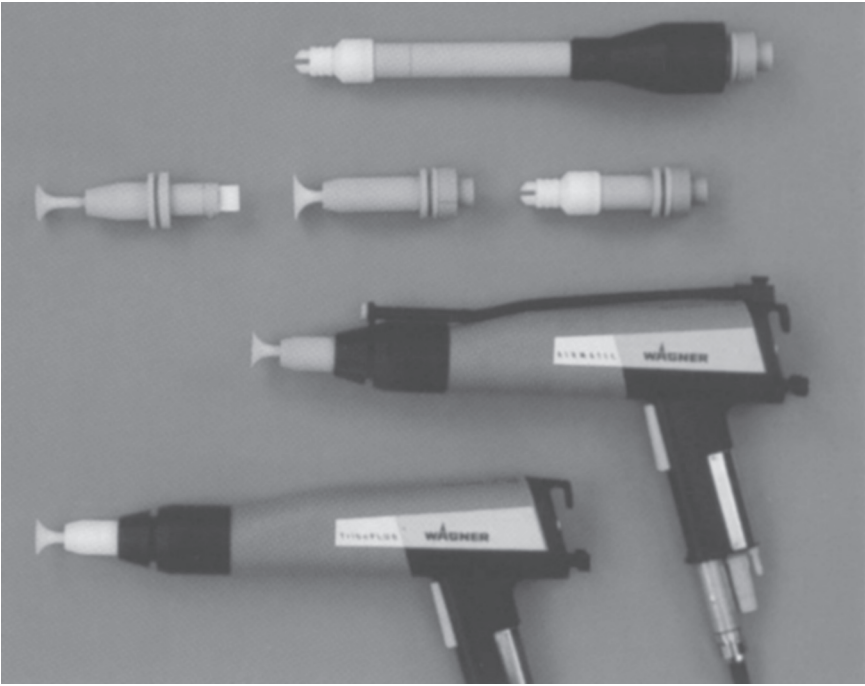


Figure 2-4. Spray gun nozzles.

Epoxy Powder Coats

Epoxy powder coats are low cost, low maintenance, and provide long-lasting protection in chemically aggressive and abrasive environments. Epoxy powders are available in a wide range of formulations, allowing them to be applied as thick films for functional purposes and thin films for decorative purposes. Typical applications are internal insulators for automobile alternators, distribution piping in gas and oil fields, and rebar for highway and bridge decks, as well as the following:

- automobile springs,
- bathroom fixtures,
- bus seat frames,
- business machines,
- dryer drums,
- fertilizer spreaders,

Table 2-1. Properties of common thermosetting powder coatings

Property	Epoxy	Hybrid	Polyester Urethane	Polyester TGIC	Acrylic
Application thickness mil (mm)	1-20 (0.025-0.508)	1-10 (0.025-0.254)	1-3.5 (0.025-0.089)	1-10 (0.025-0.254)	1-3 (0.025-0.076)
Cure cycle ° F (° C)	450 (232) 10 min	450 (232) 10 min	400 (204) 10 min	400 (204) 10 min	400 (204) 10 min
Metal temperature ° F (° C)	350 (177) 25 min	250 (121) 25 min	320 (160) 25 min	300 (149) 25 min	350 (177) 25 min
Outdoor weathering	Poor	Poor	Very good	Excellent	Very good
Pencil hardness	HB-7H	H-2H	HB-3H	HB-6H	2H-3H
Direct impact resistance lbf/in. (Nm)	60-160 (6.8-18.1)	80-160 (9.0-18.1)	60-160 (6.8-18.1)	60-160 (6.8-18.1)	20-140 (2.3-15.8)
Adhesion	Excellent	Excellent	Excellent	Excellent	Excellent
Chemical resistance	Excellent	Very good	Good/ very good	Good/ very good	Good
Mandrel bend	Excellent	Excellent	Excellent	Excellent	Poor
Salt spray resistance (hr)	1,000	1,000	1,000	1,000	1,000
Application ease	Very good	Excellent	Very good	Excellent	Good
Corrosion resistance	Excellent	Very good	Good	Very good	Very good

- fire extinguishers,
- furnaces,
- garden tools,
- hospital equipment,
- instrument cases,
- kitchen furniture,
- microwave ovens,
- mixers and blenders,
- office furniture,
- oil filters,
- power tools,
- primers,
- refrigerator racks and liners,
- room air conditioners,
- screening,
- sewing machines,
- shelving,
- sweepers,
- toolboxes,
- toys, and
- transformer cases.

Epoxy powders can be formulated for fast curing. Advancements in the cross-linking chemistries of epoxies have broadened their range of baking times and temperatures. Some epoxies can be baked at temperatures as low as 250° F (121° C) for 20–30 minutes; shorter curing times can be achieved at higher temperatures. Fast-curing epoxies may require cool environments during storage and shipping.

Most epoxy powder manufacturers specify a thin-film thickness of 1–3 mil (0.025–0.076 mm). Films in this range produce highly attractive coatings with various glosses or textures and can provide toughness, corrosion resistance, flexibility, and adhesion—all characteristics of the epoxy resin family.

Despite their excellent mechanical and resistance properties, epoxy coatings will chalk and yellow when exposed to ultraviolet light. Consequently, epoxy coatings are restricted to interior applications. Some advantages of epoxy powder coatings include:

- excellent chemical resistance,
- low-gloss finishes,

- smooth coatings,
- good corrosion resistance,
- excellent adhesion to the substrate,
- excellent electrical properties, and
- good abrasion resistance.

Some disadvantages of epoxy powder coatings include:

- chalks when exposed to ultraviolet light and
- poor gloss retention.

Epoxy-polyester Hybrid Powder Coats

Epoxy-polyester hybrids provide thin-layer coatings that cure similarly to epoxies. They can provide a coating thickness of 1–3 mils (0.025–0.076 mm) using colors with good hiding power. They are currently suitable for indoor applications only, but advances in polyester and acrylic resins have improved their exterior durability. Thin films, such as 0.5 mils (0.013 mm), may require special powder grinds.

Epoxy-polyester hybrids were introduced in the United States in the mid-1970s and were designed to provide an economical alternative to epoxies. They are an excellent, all-purpose interior coating. Hybrids are designed for use on interior products and—like the epoxy family—should be considered primarily for thin-film decorative use. Typical applications include:

- air conditioners,
- air filters,
- computer equipment,
- fire extinguishers,
- hot water heaters,
- oil filters,
- power tools,
- primers,
- shelving, and
- toolboxes.

Because of their epoxy component, hybrid powders chalk and fade when exposed to ultraviolet (UV) light, so they are unsuit-

able for exterior applications. The polyester component increases resistance to yellowing upon overbaking and contributes to improved UV resistance. Hybrid powders provide a somewhat softer surface than epoxy powders.

Hybrid powders' corrosion resistance properties are similar to epoxy powders, but their resistance to solvents and alkali is generally inferior to pure epoxies. They have superb charging capabilities, which means that the first-pass transfer efficiency is excellent with good penetration into corners and recesses. Some of the advantages of epoxy-polyester hybrids include:

- good adhesion,
- high resistance to yellowing,
- no volatile compounds emitted during curing,
- excellent transfer efficiency,
- excellent wrap-around properties,
- good intercoat adhesion,
- less sensitive to substrates,
- good mechanical properties, and
- good resistance to salt spray.

Some of the disadvantages of epoxy-polyester hybrids include:

- poor resistance to UV light and
- softer films than epoxies.

Urethane-polyester Powder Coats

Urethane-polyester powder coats are designed for decorative and protective applications requiring surface smoothness and durability. They provide toughness and resistance to weathering, as well as an excellent appearance due to their thin coating capabilities. The following are typical applications for urethane polyesters:

- air conditioners,
- chrome wheels and trim,
- fence fittings,
- fluorescent lighting fixtures,
- garden tractors,

- ornamental iron,
- patio furniture,
- playground equipment,
- range side panels,
- restaurant furniture,
- steel and aluminum wheels, and
- transformer cases.

The chemistry of urethane polyesters enables them to perform well in thin coats, usually 1–3 mil (0.025–0.076 mm). Their capacity for thin-film building, however, may contribute to inadequate edge coverage. Some of the advantages of using urethane polyesters include:

- good resistance to salt spray,
- wide range of colors,
- smooth coatings,
- low-gloss finishes,
- ability to withstand more than the recommended cure schedule without yellowing, and
- excellent gloss retention.

In addition, urethane polyesters are a good anti-graffiti product. Some of the disadvantages of using urethane polyesters include:

- some release volatile compounds on curing,
- limited capacity to build thick films,
- lack of edge coverage, and
- slight discoloration may occur on exposure to infrared rays (aromatic only).

Polyester-triglycidyl Isocyanurate Powder Coats

Polyester-triglycidyl isocyanurate (TGIC) powder coats are designed for decorative and protective applications requiring exterior durability. The following are typical applications:

- air conditioners,
- aluminum extrusions,
- automotive trim,
- irrigation piping,

- lawn and garden equipment,
- outdoor furniture,
- playground equipment,
- steel wheels,
- transformers, and
- wire fencing.

Polyester-TGIC powders can be formulated to provide good resistance to chemicals and solvents, out-gas caused by substrate porosity, scratches, and Faraday Cage Effect. (The Faraday Cage Effect occurs when charged powder is attracted and pulled to the closest ground, making it difficult to apply powder in corners.) These powders normally apply easily, and a thick film-build can be accomplished without effort. They provide good edge coverage.

Polyester TGICs employ a low-molecular-weight glycidyl as a curing agent to co-react with the polyester (unlike epoxy-polyester hybrids, which employ a conventional epoxy resin for co-reaction). In polyester-TGIC powders, the polyester constitutes a high percentage of the resin and provides weathering capabilities comparable to urethane-cured polyesters. Some advantages of using polyester-TGIC powders include:

- excellent gloss retention,
- excellent overbake color stability,
- good mechanical properties at a high film build,
- good resistance to salt spray,
- wide range of colors, and
- releases no volatile compounds during curing.

Some disadvantages of using polyester-TGIC powders include:

- difficult to produce low-gloss finish,
- difficult to produce smooth coating at a low film build, and
- less resistance to solvents than urethane.

Many powder suppliers now offer a superdurable polyester-TGIC powder in which the resin package is completely different than that in normal TGIC powders. These superdurable coatings have exceptional stability when exposed to UV, but this property comes at an increased cost. To obtain the best overall UV protection, this may well be the best powder choice.

Acrylic Powder Coatings

Acrylic powder coatings are used for their appearance and resistance to abrasion and impact. Typical applications include automotive primers, trim, and topcoats; motorcycles; and appliances. Acrylic powder can be applied in thin coats to provide a smooth topcoat without the orange-peel surface typical of some powder coatings.

Acrylics provide good resistance to alkali. Most acrylic powders are urethane acrylics. Other acrylics include glycidyl and epoxy acrylics. Urethane acrylics were developed to provide exterior durability. They demonstrate extremely good electrostatic spray properties.

In general, acrylics are more sensitive to substrate quality than other thermoset powder coatings, and most are not compatible with other coating chemistries. To prevent contamination when spraying, the use of an environmental room is recommended.

Very high gloss and clear acrylic powders can be heat sensitive and, therefore, may need to be stored and shipped in air-conditioned environments. The advantages of using acrylic powders are:

- smooth surface,
- thin film-building capacity,
- good chemical resistance,
- good corrosion resistance,
- good mechanical properties, and
- excellent gloss retention.

The disadvantages of using acrylic powders are:

- poor mechanical properties (acrylic urethane),
- higher price,
- storing and shipping environments may need to be cooled, and
- short shelf life.

CONCLUSION

Industry has made dramatic advances in developing polyester and acrylic resin systems with excellent long-term weatherability

to meet extended manufacturer warranties. Currently under development, fluorocarbon-based powders will match or exceed the weatherability of liquid fluorocarbons and result in cost savings. New silicone powder coatings are used to finish products that generate significant heat, such as commercial lighting fixtures and grills. Powder manufacturers continue to perfect resin and curing-agent designs. Current research efforts are focused on developing and improving powders that cost less and cure at lower temperatures to enable powder-coating processes to be used in a wider range of applications, such as those requiring high weatherability and resistance to chalking and fading in sunlight.

REFERENCE

Wick, Charles and Veilleux, Raymond F., eds. 1985. *Tool and Manufacturing Engineers Handbook*, Fourth Edition. *Volume 3: Materials, Finishing, and Coating*. Dearborn, MI: Society of Manufacturing Engineers.

Calculating Coverage and the Cost of Powder Coatings

COST

The cost of powder—critical to the success of powder coating applications—is a function of two variables. One, of course, is the manufacturer's price for the powder. The other is the powder's coverage. A powder's coverage depends on the specific gravity of the powder, the transfer efficiency of the process, and on the required coating thickness. (The term *specific gravity* describes the weight or density of a liquid compared to an equal volume of fresh water at 39° F [4° C].) Powder coverage is measured in square feet, square meters, etc.

Transfer Efficiency

Basically, transfer efficiency is an easy percentage calculation, that is, *transfer efficiency* is expressed as the amount of powder sprayed divided by the amount that adheres to the part. Bear in mind that actual transfer efficiency is always less than 100% because some sprayed powder does not adhere to the substrate. For example, if 10 lb (4.5 kg) of powder is sprayed at a substrate and 5 lb (2.3 kg) adheres to the substrate, the transfer efficiency is 50%.

Generally, it can be assumed that 100% transfer efficiency when applying powder to the part would never be achieved. Since the powder coming out of the paint gun is charged and forms some cloud pattern, the transfer efficiency continually changes. Some major factors entering into transfer efficiency include:

- charging capability;
- the amount of powder exiting the gun;
- grounding of the part;
- the kilovolts of the corona field through which the powder passes before landing on the part, and
- the distance the operator holds the gun from the part.

When spraying powder, 193.2 ft² (18.0 m²) of the part can be covered to a thickness of 1 mil (0.025 mm) when one 1 lb (0.5 kg) of powder is sprayed at 100% transfer efficiency. So, powder coverage has a number of factors. Put as a mathematical equation:

$$P_c = \frac{193.2}{S_g} \times T_e \quad (3-1)$$

where:

P_c = powder coverage, ft² (m²)

S_g = specific gravity

T_e = transfer efficiency, %

For example: At 100% transfer efficiency, 1 lb (0.5 kg) of powder with a specific gravity of 1.5 will cover 128.2 ft² (11.9 m²) at a thickness of 1 mil (0.025 mm).

Typically, 2–3 mil (0.051–0.076 mm) of powder is applied to the substrate, so to determine the actual coverage per pound (per kg) it must be divided by the thickness required. Table 3-1 shows powder coverages at 100% transfer efficiency for various coating thicknesses and powder-specific gravities. For example, if the transfer efficiency is 60%, the equation looks like this:

$$77.28 = \frac{193.2}{1.5} \times 60\%$$

and only 77.28 ft² (7.2 m²) are covered.

Table 3-1. Powder coating coverage at 100% transfer efficiency

Specific Gravity	Thickness		
	1 mil (0.025 mm)	2 mil (0.051 mm)	3 mil (0.076 mm)
1.0	193.2 ft ² (18.0 m ²)	96.6 ft ² (9.0 m ²)	64.4 ft ² (6.0 m ²)
1.1	175.6 ft ² (16.3 m ²)	87.8 ft ² (8.2 m ²)	58.5 ft ² (5.4 m ²)
1.2	161.0 ft ² (15.0 m ²)	80.5 ft ² (7.5 m ²)	53.7 ft ² (5.0 m ²)
1.3	148.6 ft ² (13.8 m ²)	74.3 ft ² (6.9 m ²)	49.5 ft ² (4.6 m ²)
1.4	138.0 ft ² (12.8 m ²)	69.0 ft ² (6.4 m ²)	46.0 ft ² (4.3 m ²)
1.5	128.8 ft ² (12.0 m ²)	64.4 ft ² (6.0 m ²)	42.9 ft ² (4.0 m ²)
1.6	120.8 ft ² (11.2 m ²)	60.4 ft ² (5.6 m ²)	40.3 ft ² (3.7 m ²)
1.7	113.6 ft ² (10.6 m ²)	56.8 ft ² (5.3 m ²)	37.9 ft ² (3.5 m ²)
1.8	107.3 ft ² (10.0 m ²)	53.7 ft ² (5.0 m ²)	35.8 ft ² (3.3 m ²)
1.9	101.7 ft ² (9.5 m ²)	50.9 ft ² (4.7 m ²)	33.9 ft ² (3.1 m ²)
2.0	96.6 ft ² (9.0 m ²)	48.3 ft ² (4.5 m ²)	32.2 ft ² (3.0 m ²)
2.1	92.0 ft ² (8.6 m ²)	46.0 ft ² (4.3 m ²)	30.7 ft ² (2.9 m ²)
2.2	87.8 ft ² (8.2 m ²)	43.9 ft ² (4.1 m ²)	29.3 ft ² (2.7 m ²)

MAKING PURCHASE DECISIONS

Powder prices vary depending on specific formulations, performance properties, and manufacturers. Prior to selecting the powder to purchase for a specific application, the end user must:

- clearly identify the performance properties required for the application;
- determine the powders meeting those requirements, and
- compile a list of manufacturers providing these powders (and at what cost).

Account managers for powder manufacturing companies provide an enormous amount of information during this investigative phase. Since significant cost differences can exist among powder formulations, the proposed powder's cost can be a determining factor when making the purchase decision. In other words, before purchasing from a particular powder manufacturer, be sure to do the homework, ruling out powders and powder manufacturers who do not meet the project's needs.

A good relationship with the account manager from the powder manufacturer/supplier is a must once a decision on the most suitable powder for the particular application is reached. Good account managers will visit their customers on a regular basis to discuss their product with purchasing personnel, painters, line personnel, supervisors, and managers, as well as to assist with troubleshooting and training. In this way, both the end user and account manager can address problems early in the process. When this crucial service is omitted, account managers may only hear about problems through purchasing personnel, and perhaps only after another manufacturer has been called to solve the problem. Many times, powder-coating problems can be pinpointed easily. Insist on good quality service from product account managers.

Manufacturers typically quote powder coating materials by the pound (kg). When comparing price quotes for a specific powder, take the time to figure the coverage per pound (per kg) for each powder being quoted to ensure accurate comparison.

Powder Process and Electrostatic Theory

Powder spray guns impart an electrostatic charge to powder particles as they pass through the spray gun on their way to the part. The gun controls allow varying gun position, velocity, shape of pattern, and charge levels to direct the powder's deposition on the part.

Powder spray guns are manual (handheld) and automatic (fixed mount), internal and external charging, corona charging with internal or external high-voltage supplies, and triboelectric (frictional charge). These variations have their advantages, their weaknesses, and their particular roles in painting parts.

CORONA CHARGING AND TRIBOCHARGING

The *corona* is a highly charged field concentrated at the electrode or end of the gun. Through the use of high-voltage output supplies, corona charging is accomplished.

Successful powder coating depends on effectively charging the surface powder particles' surfaces. A high voltage of 30–100 kilovolts (kV), and usually a negative polarity, is applied to the charging electrode. This voltage creates a strong electric field around the electrode. In turn, the strong electrical field causes a breakdown (ionization) of the air around the electrode to form a corona

discharge and an ion current. The electric field directs the ions to the powder particles. The electric field is bombarded by the ions, transferring charge to the particles. The velocity of the air from the pump and the electric forces (to a lesser degree) carries the charged particles to the part.

Many times, ions from the external field can no longer reach the particle because the particle's field repels them. In this case, the particles have reached maximum charge, given the external field strength, particle size, and material.

Once charged particles approach the part being painted (to within 0.394 in. [1 cm]), the attraction between the charged powder particles and the grounded part causes the particles to effectively deposit on the part.

Most materials used for powder coatings are strong dielectrics. Once charged, the charge does not “bleed off” quickly. In fact, most materials used for powder coating retain a charge for at least several hours, even if the material's small particles are placed on the grounded metal surface.

When a charged powder particle is positioned next to the metal surface, it induces a charge of equal value, but opposite polarity, inside the metal. These two charges not only attract and hold the powder particle to the metal surface, but they also create another electric field between them. Figure 4-1 shows the electric field between two charges.

Larger powder particles on the metal surface with a higher charge create a stronger electric field between the particle and its mirror image. Thus, the stronger the electrostatic attraction is between them. Because larger particles experience a stronger attraction to the grounded metal, the orange peel effect on thicker layers of powder coatings can be observed. (The orange peel effect is an irregularity in the surface of a coating film resulting from the inability of the film to level out.)

Larger particles are likely to be deposited on top of existing uncured coating. When viewing a cross-section of an uncured powder-coating layer, the bottom portion (closer to the metal) would likely have a smaller average particle size than the top portion. A powder coating may not flow well during the curing process. The larger particles—comprising the upper coating layer—may not completely flow out and thus remain on the surface profile of an

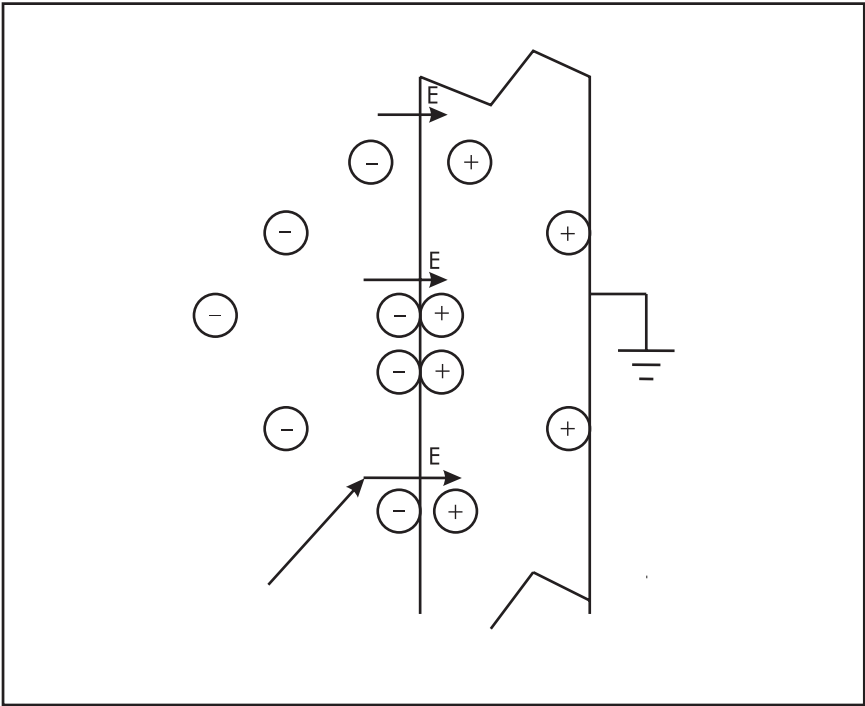


Figure 4-1. Electric field between two charges.

uncured coating layer. This results in lower gloss, bumpy finishes, and orange peel due to the insufficient flow properties of the powder coating (Guskov 1996).

Free ions are negative ions produced by the corona ionization process. Powder particles do not capture these free ions. They remain free in the space between the gun and grounded part and travel toward the closest ground along the field lines.

BACK IONIZATION, FINISH QUALITY, AND TRANSFER EFFICIENCY

Back ionization is probably the painter's worst application problem. When a painter attempts to apply powder into recessed areas, the charged powder particles tend to attach themselves to the closest ground. Unfortunately, the closest ground is not usually where the painter wants the powder to be applied. Back ion-

ization is also a major cause of what is termed the “self-limiting” property of powder coating, because it greatly reduces transfer efficiency. Adjacent surfaces to the inside corners attract the charged powder.

Due to mirror polarities, spraying charged powder on the same surface provokes back ionization.

When charged powder coating is applied to a metal surface, the strength of the electric field inside the powder-coating layer increases. Every new particle deposited increases the:

- cumulative charge of the powder-coating layer;
- cumulative mirror charge inside the metal; and
- strength of the electric field inside the layer of powder coating.

As charged powder continues to be applied, the strength of the electrical field inside the powder-coating layer ultimately becomes sufficient to ionize air trapped between the powder particles. The resulting intensive flow of electrons and ions causes streamers to develop through the powder-coating layers. A *streamer* can be viewed as miniature lightening or a spark shooting through the powder-coating layer. Inside a streamer, numerous electrons and positive ions travel in opposite directions. Once the finishing process is complete, streamers can be seen as starbursts on the surface.

Back ionization is a common cause of orange peel on powder-coated surfaces. As the positive ions produced by back ionization inside the powder-coating layer move out of the coating layer, they neutralize the charge of the powder particles adjacent to the streamer channels. The active directed motion of positive ions along streamer channels also engages air molecules, resulting in a phenomenon called *electric wind*. Electric wind rips powder particles neutralized by positive ions from the powder-coating layer. This action creates “micro craters,” easily visible on the uncured powder-coating surface in the form of “starring.” If the powder-coating material does not flow well during the curing process, craters formed by back ionization will not flow over completely, resulting in the wavy surface appearance of the cured powder coating.

A quick analogy of back ionization includes the following example. Take a bucket with a small hole in the bottom and try to

fill it with water from the faucet. It takes some time for the bucket to overflow. The water represents the stream of charged powder particles building a powder-coating layer. Water in the bucket represents the charge accumulating on the layer. The water leaking through the hole in the bottom of the bucket represents the small amount of charge possibly bleeding off the coating. The overflow represents the onset of back ionization.

It is important to remember this analogy when recoating a cured powder. If the metal substrate has a powder-coating layer, this layer partially insulates the metal surface, restricting the flow of the charge delivered by free ions to the ground. The charge not bleeding to the ground dramatically increases the cumulative charge of the coating layer, resulting in rapid development of back ionization, significant reduction in powder transfer efficiency, and a deterioration of finish quality and uniformity.

Poorly grounded parts can cause back ionization. Turning down the voltage and adjusting the amps can assist in overcoming the problem. In some cases, preheating the part allows the powder particles to fuse immediately without regard to the charge.

FARADAY CAGE EFFECT

During electrostatic powder coating, the high-voltage potential applied to the tip of the gun's charging electrode creates an electric field between the gun and grounded part. This leads to the development of corona discharge. A great number of free ions—generated by the corona discharge—fill the space between the gun and part. Powder particles capture some ions, thus charging the particles.

A cloud of charged powder particles and free ions created in the space between the gun and part has some cumulative potential called *space charge*. This cloud creates an electric field between itself and a grounded part. Therefore, in a conventional corona-charging system, the electric field close to the part's surface is comprised of fields created by the gun's charging electrode and the space charge. Combining these two fields facilitates powder deposition on the grounded substrate, resulting in high-transfer efficiency.

Positive effects of the strong electric fields created by conventional corona-charging systems are most pronounced on parts with large, flat surfaces being coated at high conveyor speeds. Unfortunately, the stronger electric fields of corona-charging systems can have negative effects in some applications. For example, when coating parts with deep recesses and channels, the Faraday Cage Effect is observed.

When a part has a recess or a channel on its surface, the electric field follows the path of the lowest resistance to ground. Unfortunately, two negative effects accompany this process. First, since the electric field strongly pushes the powder particle field toward the edges of the Faraday cage, fewer particles can intrude the recess. Second, free ions generated by the corona discharge, following field lines toward the edges, quickly saturate the existing coating with extra charge, and lead to rapid development of back ionization.

It was established earlier that for powder particles to overcome aerodynamic and gravity forces, and be deposited on the substrate, a sufficiently strong electric field must assist in the process. Clearly, neither the field created by the gun nor the part penetrates inside the Faraday cage. Therefore, the only source of assistance in coating the inside of recessed areas is the field created by the space charge of powder particles delivered by the air stream inside the recess.

Authorities on powder disagree on ways to combat the Faraday Cage Effect. Some feel the voltage of the gun should be lowered so less attraction occurs and that the powder velocity should be raised to reach the corners. It is important to note: when raising velocity and reducing voltage, the volume of powder must be reduced dramatically or the powder will not take on a charge and will fall into the corners. Others feel that keeping the voltage as high as possible and working on the aerodynamic aspects of the transportation will maintain a higher charge level on the powder and result in more efficient coating of the cavity.

Small conical defectors applied for interior usage are most effective when dealing with caging problems. Smaller defectors permit a decrease in the powder volumes and velocity rate to ef-

fectively deal with most situations. There is no one, set way to deal with Faraday caging. There are many variables including the properties of each substrate being painted, the type of application equipment, the powder itself, and the style of application. And they all play a role in dealing with Faraday cage areas.

FREE ION COLLECTION (IC) DEVICE

The principal behind the operation of an ion collecting (IC) device is that it extracts free ions from the space between the gun and part, and draws them to a grounded electrode positioned behind the gun's tip.

It is important to have the ion collector positioned so it won't interfere with the normal electric field. If the powder is well charged, transfer efficiency will not suffer and the ability to penetrate recessed areas is greatly enhanced.

The easiest rule is to place an ion collector behind the tip of the gun at no more than half the distance between the gun and the part. If the ion collector is properly set up, it often delivers impressive improvements in Faraday cage penetration, and finish quality and uniformity. Reduction of transfer efficiency is likely to occur with ion collectors located too close to the gun's tip due to changes in the size of the charge zone.

The free ions generated by conventional corona charging equipment cause problems such as Faraday cage penetration and recoating of rejects.

Regardless of the type of gun being used, the transport of well-charged particles to within 0.394 in. (1 cm) of the surface is essential for efficient and effective powder coating.

By far, the external corona gun is the most common type in use today. It has good uniformity and transfer efficiency.

In cases where there may be a great number of collisions of parts with the guns, there is the potential for damage to a high-cost component in the gun (the generator).

Skilled powder coating applicators can make the internal and external systems deliver equal performance when painting.

HIGH-VOLTAGE POWER GENERATION

In corona-charging systems, high-voltage power supplies generate an electrostatic field. The first stage is an adjustable DC-power supply in the control box driving the oscillator. This, in turn, feeds the high-voltage transformer, increasing the low voltage at the oscillator to approximately 10 kV. Oscillation of the voltage is needed since both the transformer and multiplier require an AC-voltage signal to operate. The last stage is the high-voltage cascade, or multiplier. At this state, voltage increases into the 75–100 kV range.

INTERNAL AND EXTERNAL CHARGING GUNS

As stated earlier, external corona guns are the most common powder spray guns. In an external charge corona gun, ion bombardment close to the charging electrode charges the powder. This voltage creates a strong electric field around the electrode, and the air around the electrode breaks down (ionizes) to form a corona discharge and an ion current. The field to the powder particles, which are bombarded by the ions, transfers the charge to the particles.

In an internal gun, the charging process is the same as in an external gun. However, while the charging electrode is referenced to the grounded part to form the corona in an external gun, the internal charge carries its own ground reference internally. Little or no external field forces and excess ion current result.

Internal charging corona guns tend to require more frequent maintenance than other guns. It is necessary to keep their ground reference clean and free of powder, due to their complex and often fragile components. Internal guns weigh more than their external counterparts because the multiplier is located in the gun. The external multiplier in other guns is located in the control module.

Internal guns have lightweight cables and external guns have thicker, stiffer, heavier high-voltage cables.

Tribocharging

Triboelectric guns have no high-voltage power supply. Frictional rubbing of the powder in long spiral tubes in the gun generates tribocharging. The powder for tribocharging must be specifically formulated for tribo equipment. The tribocharge is positive and has no “field” to pass through.

Generally, deposition rates are lower for tribo guns, so more guns per line are required. Since the charging process depends on inertial forces bringing the particles in contact with the walls, and since the charge transfer is related to the relative chemical compatibility of the powder and the wall material, the process is sensitive to both the particle-size distribution and the chemistry of the powder being sprayed. Some powder cannot be sprayed. Also many colors may not be applied unless designed for tribo application. This is because tribo has to charge the particles via friction and the particles may not charge.

Most tribo guns are made of PTFE (polytetrafluorethylene or Teflon®). Almost anything rubbed on PTFE will be charged positively. This material has low-flow friction, wears well, and strongly resists being coated by the powder material.

There are many types of impact design for tribo equipment. A characteristic of the tribo gun is that it produces a flow of charged powder with little external field and no excess ion current. The absence of a field helps in the penetration of Faraday cage areas.

If the equipment is performing inadequately, ask the equipment supplier to conduct a test with a DC-voltage test meter. This meter provides a high-voltage test of electrostatic output. The meter is an inexpensive device to monitor output and could prevent a shut-down. Problems from poor output can be equated to poor transfer efficiency.

Controllers

The controller houses portions of the charging system for spray guns. Gages control feed hopper fluidity, the volume of powder

delivered to the application gun(s), and the velocity of the powder through the gun and charging corona. It is important to locate controllers in proximity to the painters so easy adjustment of the application can be made. However, the controller(s) should not be placed where powder particulate might migrate to inside the controller.

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Powder Curing and Ovens

HEATING FUNCTIONS

The thermosetting powder's chemical reaction begins in ovens. Ovens produce and maintain heat—the sole cause of the chemical reaction needed in powder coating. Powder-coated parts must be exposed to heat to achieve the user-specified properties. The proper amount of heat at a given time ensures that the desired decorative, chemical, and mechanical properties are realized.

Since many powder-coating operations are also high-speed production operations, heating functions must be carried out in the most efficient and cost-effective manner. A particular application's requirements must be thoroughly studied and matched with the oven's capabilities. Therefore, thoroughly investigating each aspect of the heating components of a powder finishing line is critical to achieving an efficient, effective, and satisfactory operation.

Ovens are an important component in the powder-paint system. They must work properly to ensure worker safety and consistent results in the curing process. Ovens should never be operated if they are working improperly.

A quality oven should possess the capacity to efficiently operate slightly above its ambient temperature to its rated maximum temperature (as well as any point in between). The oven should be able to withstand the rigors of long, high-temperature, cycling

times. Many ovens work directly with airflow to maintain efficiency and to heat a part. Not all airflows are equal. Different processes require different airflow patterns, as shown in the following examples:

- Horizontal/vertical airflow is ideal when working with large parts, when a process needs air circulation from both sides, and before the air returns to the top of the oven.
- Vertical airflow is best suited for processes where parts are hung from racks or hooks, and with the air supplied from the floor and returned to the top of the unit.
- Full horizontal airflow is most applicable when the product is loaded onto shelves or a shelf cart for processing. Since the air supply is on one side and the return duct on the other, the product becomes encircled with air.

Uniformity

Conducting a powder-coating process within a temperature range is important because a uniform temperature helps ensure an evenly coated product.

Webster's dictionary defines *uniformity* as "the quality or state of being uniform," and it further defines *uniform* as "having always the same form, manner, or degrees; not varying or variable." However, while uniformity would imply a strictly identical temperature, some temperature deviation is possible. Within a certain range, this deviation could still be termed "uniform" by the powder-coating industry. Thus, uniformity allows spread or deviation, in degrees, between the highest and the lowest points within the temperature needed for successful powder coating. For example, it is important to note that $\pm 5^\circ$ actually represents an actual difference of 10° F (-12° C). Many influences on the temperature uniformity include:

- controller calibration;
- sensor calibration;
- sensor placement within the work area;
- oven temperature (higher temperature/greater variables);

- circulation (the greater the air circulation, the better the uniformity);
- placement of the workload within the work area;
- airflow pattern;
- heat loss through the walls; and
- metal-to-metal conduction.

Uniformity should not be confused or mistaken for control sensitivity. *Control sensitivity* is the ability of a control instrument to not only measure, but to also react to temperature fluctuation at a given set point.

Oven Considerations

Some considerations in designing an oven are:

- the dimensions of the parts to be cured;
- the proper working space between the parts;
- the proper spacing between the parts, the duct work, and the oven housing; and
- the quantity of parts to be processed in a single batch.

A work area with an inadequate amount of space between the parts results in poor airflow and less-than-optimal oven performance. When the workspace is too large, there is an excess of space to heat and circulate air through. This wastes energy, space, and most importantly, time.

There are three ways to heat parts to the temperature required to properly cure a powder coating on a metal:

- convection—a transmission of energy caused by air circulation to heat the part;
- radiation (also called infrared radiation)—a transmission of energy directly to the part, without heating the air between the part and radiation source; and
- induction—a transmission of energy resulting from inducting electrical eddy currents to generate heat in the metal part.

The nature of the part and the requirements of the coating dictate a preference to a certain cure oven. The process considerations are:

- the product—size, configuration, mass, and temperature limitations;
- the conveyor—method, product holder, and line speeds; and
- the powder—formulation type, thickness, cure profile, color, gloss, and tests for cure.

Many companies have changed—or are changing—to multi-combination heating techniques. This newer technology in curing ovens has produced dramatic improvements in the last few years. Many infrared/convection combination ovens are in factories and these ovens provide:

- quick initial coating flow;
- reduced cure times;
- reduced oven lengths; and
- higher-quality finishes in some cases.

Convection

In convection heating, air is the medium to transfer heat from the energy source to the product. Many convection systems use a fuel source (gas, oil, or steam) to provide heated air circulation in the oven chamber. In a combustion chamber, the oven atmosphere can contain combustible products and possibly some traces of unburned fuel. Gas is the most widely used fuel source as it is readily available and cost effective.

Convection ovens are like most ovens that are seen in homes. They are no more than an insulated shell with an appropriate heat source. A convection oven heat source comes from a burner box (sometimes called a “doghouse”). The burner box can be mounted on top, under, on the side, or in the oven. These burner boxes require a high flame directed toward a fan blowing the heat into the oven for cure. The presence of this directed heat means the oven is “direct fired.”

Exhausting the Oven

Cure ovens must expel exhaust to remove the by-products of cure and combustion. Users must purge the oven of raw gas be-

fore burner ignition, maintain control of the oven temperature, and prevent accumulation of fumes. The pipe of the exhaust system should be large enough to vent the entire oven air volume several times per hour (typically exhausting 10 times [minimally] per hour). Certain colors and surface profiles, such as textures and their combustion by-product, dictate the necessity of turn-overs in the required exhausts. Darker colors need fewer turn-overs than “clears” or lighter colors.

Exhaust fans purge raw gas from the oven during startup operations. They vent residual smoke from the oven to the outside, rather than letting it enter the plant. A balanced oven operates more efficiently because heat does not leak from the oven chamber and openings.

Energy

Insulating the oven panels properly saves energy because less heat escapes from the oven. It is fairly cheap to add extra insulation. Some energy companies give rebates according to the energy saved from the added improvements. Floors as well as the oven shell should be panelized to prevent heat loss and cracking.

There can be many design feature options for a convection oven. Some considerations include:

- Internal structural steel should use bolted clips and welded construction with slotted bolt holes to allow for oven expansion.
- Steel should support additional conveyor work and the workloads.
- The structural support column should be anchored to the building floor.
- Since oven heat rises naturally, some companies prefer to install ovens at ceiling height. This enables the parts to enter and exit under the oven rather than into an opening on the side of the units. A bottom entry/exit oven creates a natural heat seal, and is the most energy efficient design. This design leaves more available floor space below the oven.

The oven should have a smooth interior to aid cleaning and maintenance. Topcoat contamination builds in an oven. Less protrusions

within the oven mean easier and quicker cleaning. After cleaning, dust, debris, and particulate are dislodged at times and become airborne. In most ovens with ducts, the majority of debris resides in the outer ends of the ductwork as the natural momentum of the air pushes the debris to the path of least resistance. This does not mean only certain areas need cleaning. All ductwork needs cleaning. Some products cannot tolerate contamination and may need curing in a wash-down-style oven. In this oven, drains are strategically placed and the oven can be cleaned and washed with water. Oven panels should be tongue-and-groove design with 4–6 in. (10–15 cm) of insulation. More insulation keeps heat within the oven and keeps the outside plant temperature lower. This is especially important when the plant is air-conditioned. Other important tips to remember include:

- Construction should provide 16–20-gage aluminized or steel interior and exterior skins secured to 18-gage galvanized steel-formed channels.
- Floor panels should be constructed of 20-gage material with internal skin stiffeners for added strength.
- Floors should be insulated to increase operating efficiency, lower operating costs, and improve temperature uniformity within the work area (as compared to those ovens without insulated floors).
- Insulated floors do not crack and emit dust as do concrete floors.
- Insulation should be 4–6 lb (1.8–2.7 kg), density of semi-rigid mineral fiber or equal. The insulation blanket should fill the panel assembly without voids and withstand 600° F (316° C).
- Panels should be manufactured to assure a tight fit without deformation.
- Insulation strips should be installed between panel joints.
- Panel joints should be caulked inside and out with a high-temperature oven sealer that resists crumbling under normal expansion and contraction.
- Inside aluminized steel resists corrosion from moisture, heat, and other sources.
- Inside stainless steel is highly recommended when the work area is exposed to corrosive materials or must be cleaned with corrosive solutions.

- Outside cold-rolled steel, standard on most units, is usually prime/painted. Outside aluminized steel, optional on units, resists moisture-caused oxidation. Outside stainless steel is another option. This exterior not only resists oxidation, but successfully stands the test of corrosion (caused by chemical exposure).
- All oven corners and joints should be properly flashed.
- Ovens should have explosion relief panels. Relief panels should be as close as practical to 1 ft^2 (0.09 m^2) of wall and roof panel per 15 ft^3 (0.42 m^3) of oven volume with due allowance for end openings and doors with explosion relief hardware.
- Heat seals should be used to prevent heat loss through the oven conveyor openings.
- Burners for ovens should be either Maxon Ovenpak[®] 400 series or Eclipse Air Heat[®] “AH” series.
- Burners should be complete with necessary safety controls and include flame failure protection utilizing an ultraviolet scanner, a direct spark ignition, a peep sight, an automatic motorized gas valve, a gas proportional valve, a manual safety shutoff valve, high-temperature limit cutout, an airflow switch, and a continuous pilot with solenoid.

Ductwork

Ductwork is designed to provide uniform flow of the air that the fan is circulating in the heater house. (The fan is circulating the air to the entire part surface.) Dampers on the ductwork control the air as it is discharged from the duct. Partially opening some outlets and partially closing others balances the heating system, resulting in uniform and consistent heat to the part. Ductwork should be fabricated with 16–22-gage aluminized steel or steel, depending on the duct size. Necessary openings should be adjustable within each duct to minimize localized cold spots.

Ductwork should possess hinged sections for easy maintenance and accessibility.

Floor-mounted ductwork is the simplest way to distribute heat throughout the oven interior. Cleaning the interior of the duct can be difficult if panels are not installed for this purpose. It is

easy to make control corrections with the floor-mounted duct system. Floor-mounted ducts are more likely to produce contamination because they must force air upward to be heated (see Figure 5-1a).

The roof-duct system works well for heating parts and can be easily cleaned. Installation of hinges on the bottom portion of the ductwork allows for easy cleaning of the interior of the duct. Down drafting (a process of moving air downward toward the shop floor) ensures a cleaner atmosphere. Down drafting directs dirt particles toward the floor-mounted recirculation duct and into the oven filtration system (see Figure 5-1b). See the equipment's supplier for the specific operating design of the ductwork and how down drafting might be effective.

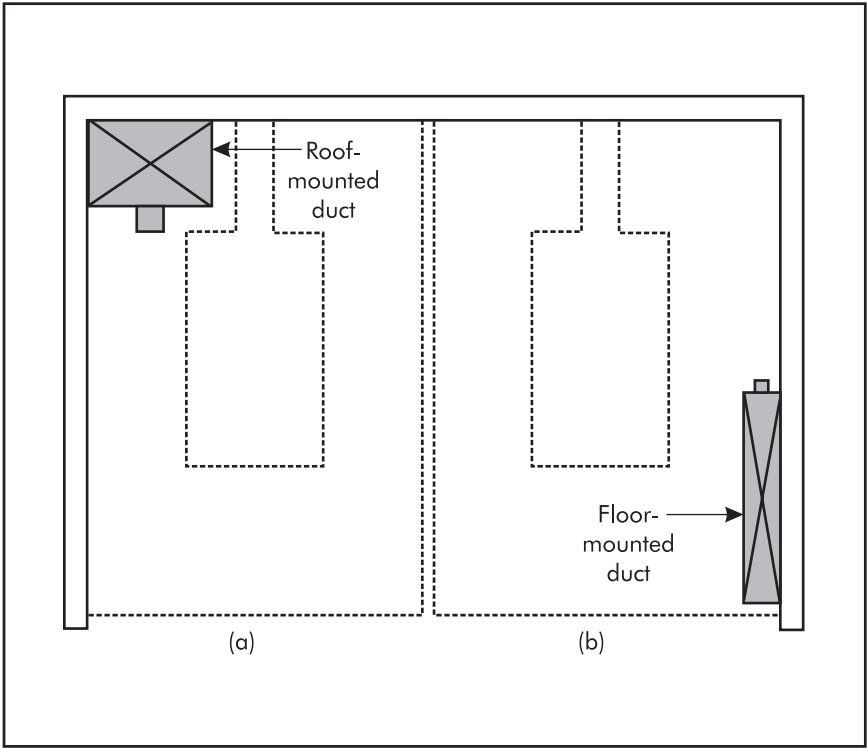


Figure 5-1. Typical roof- or floor-mounted duct system. (Courtesy Nordson Corporation)

Controller Boxes

Controller boxes allow a user to control temperatures within the oven. Some boxes control more than one oven. Controls for ovens should be easy to reach. Inside the box, circuitry controls the oven purge. Insurance companies mandate purging, therefore purge time is a significant factor to consider in a powder-coating operation. Purge time is dictated by the amount of time the oven takes to turn over four times. A flame safeguard allows the oven to ignite without purging. Some companies manually/physically bypass this feature to speed oven heating. Such a practice could prove dangerous if the oven were to develop a gas leak.

Some newer control boxes have an analog scale with set point and actual oven temperatures displayed. These newer controllers permit the user to set the high- and low-temperature alarms from a thermocouple placed inside the oven.

The controllers can process line stoppage and automatically lower the temperature so parts are not over-cured and conveyors are not cooked. This is also a good energy-saving feature when used properly.

Heater Units

The supplier of the heater unit should also supply the air-filtering equipment. This equipment consists of high-efficiency filters with frames that withstand high temperatures. The equipment is located near the burner.

Gas-fired heater units are more cost-effective to operate than electrically heated ovens. There are some processes where direct-fired gas units cannot be used. In these processes, the user should opt for an indirect-gas-fired unit (although an indirect-gas-fired unit's initial cost is much higher, it is available as a small oven or high-temperature unit).

Electrically heated units are not as costly to purchase in a Class "B" configuration (the classes of heaters are discussed later in this chapter). They are clean and nonpolluting, and can be used in applications where direct-fired gas units are not suitable.

Steam-heated units are an efficient means of power when operating in the lower temperature ranges. They are often advantageous when a facility already has a boiler in place and has extra pressure to use for an application.

Ovens relying on supply fans usually have a centrifugal-type fan with a backward-inclined wheel. This fan is designed to operate at high temperatures and is sized to provide enough air to turn over the volume of the oven at least three times per minute. Access to the oven's heater box needs to be provided for maintenance or repair. The burners contribute largely to the operating costs of the heating/curing system.

Infrared Radiation

Shortwave, high-intensity infrared heating uses electrical energy to produce a direct, radiant method of heating. Infrared radiation (IR) is transmitted directly from an emitter to the product via electromagnetic waves traveling at the speed of light (186,000 mi/s) (299,274 km/s). Unlike convection heating, high-intensity infrared requires no medium for heat transfer. Radiation is a "line of sight" method. It only cures what it "sees." Heated energy is transferred quickly, cleanly, and efficiently, typically with tungsten quartz infrared lamps. Shortwave heaters also penetrate the substrate. High-intensity infrared can have fast temperature-time response. Curing ovens using this method of radiation heating are compact in size and can be zoned to match exact product configuration and size. Figure 5-2 shows a typical infrared system.

Startup times of 10–15 minutes are common for infrared heating. Savings in energy, space, and time can be realized with high-intensity infrared if the part configuration is correct. Many companies use a preheat infrared unit in combination with a standard convection oven.

The three types of IR heat sources are:

1. Long-range emitters convert 40–50% of electrical energy into IR. Long wavelength emitters normally operate at 1,000–1,200° F (538–649° C).

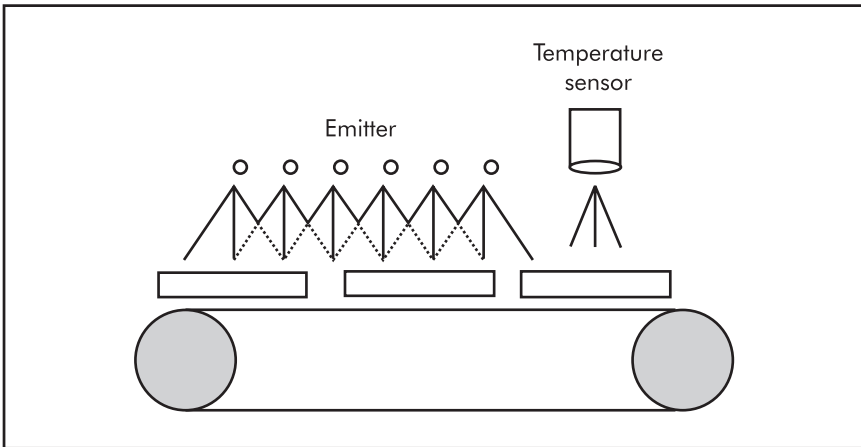


Figure 5-2. Typical infrared system. (Courtesy Nordson Corporation)

2. Medium-range emitters convert 50–60% of electrical energy into IR. Medium wavelength emitters normally operate at 1,800– 2,000° F (982–1,093° C).
3. Shortwave emitters convert over 80% of electrical energy into IR. They operate at 3,000–4,000° F (1,649–2,204° C).

Each emitter's heating rate can be raised and lowered. The shortwave emitter has the fastest heating rates. The shortwave emitter provides a rapid rate of heating, making it the most popular among the emitter types.

Induction Heating

Traditionally, induction heating is used for metal parts in application such as brazing, soldering, melting, and hardening. The power of modern induction-heating systems is controllable enough that it may be used to create ceramic components at temperatures in excess of 2,400° F (1,316° C). Induction heat can be used to cure adhesive such as that on the felt light trap of a film cassette.

A noncontact method, induction heating can be used for electrically conducting materials. Induction heating involves:

- a source of alternating current (the induction heater);
- an induction coil (often called the work coil); and
- the part to be heated (the workpiece).

When an electrical current alternates within a work coil, the process produces an alternating magnetic field inside and outside of the work coil. If an electrically conducting part is within the magnetic field, a current will develop in that part. The power that the current develops depends on:

- the induction heater's kilowatt rating;
- the workpiece's electrical resistivity; and
- the work coil configuration and its relationship to the workpiece.

DRY-OFF OVENS

Dry-off ovens dry water from parts as they exit the pretreatment system. This is a critically important process. Powder-coating processes demand a dry part surface for the powder to properly attract to the part. If powder is sprayed onto a moist surface, and the surface is cured, the surface initially appears to be normally cured, but oxidation begins immediately. A crosshatch test will catch this oxidation process. Never apply powder over any moisture. The powder coat will ultimately peel.

Dry-off ovens use higher volumes of directed air than other ovens to assist the drying process. If a part has areas that hold or trap water, it will need drainage holes. The user also needs to rethink the part's hanging method, install air knives, or a combination of each.

There should be sufficient room between the dry-off oven and the powder booth to allow the part to cool to ambient temperatures before the powder-application process. Applying powder onto a hot surface causes the powder to react and fuse, causing uncontrolled film thickness and powder waste.

Many companies use combination ovens when the dry-off oven and cure oven are located next to each other and share a common wall. This style of system requires less structural material and

takes less plant floor space. Each of these ovens usually have their own heat sources.

For some companies, one oven meets both dry-off and curing needs. Oven combinations such as this are rare because there are no divider walls between the dry-off and cure portion of the oven and because there is only one burner bow heating the oven. In this case, the excessive moisture given off from the parts being dried can create humidity problems in the cure part of the oven. Subsequently, the cure part of the oven heats the dried parts to a temperature too hot for coating.

SAFETY

The National Fire Protection Association (NFPA) has stipulated two classes of ovens. Class “A” ovens can be used with volatile compounds, and Class “B” ovens cannot be used with volatiles. Safety equipment for a Class “A” oven includes:

- airflow safety switch,
- manual reset excessive temperature control,
- backup contractors,
- 225 ft³/min (6.4 m³/min) powered exhaust, extra kW, and a purge timer.

A Class “A” gas-fired oven includes the following safety equipment:

- airflow safety switches, manual reset excessive temperature controls, and a powered exhaust (sized to the unit and burner size);
- high/low gas pressure switches;
- purge timers;
- flame safety; and
- spark ignition.

Class “B” electrically heated ovens include the following safety equipment:

- airflow safety switches;
- manual reset excessive temperature control; and
- backup contractors.

The rating of Class “A” is determined by examining the volatile gallons per hour processable at a given operating temperature. Volatile ratings are never to be exceeded. Physical injury or death may result if the volatile ratings recommendations are not strictly followed.

The two major specifications insurance companies may ask a business to meet are:

- Factory Mutual (FM)—an association of mutual insurance companies dedicated to loss prevention.
- Industrial Risk Insurance (IRI)—formerly FIA, composed of member stock insurance companies, is concerned with all phases of fire protection and other perils its members are insured against.

OVEN PROFILING

The oven profile is a tool to help evaluate the cure process. An oven-profiling system monitors the part’s temperature as it passes through the thermal process. Thermocouple sensors are attached to the product. Information from the sensors is recorded in a data logger specifically for this process (see Figure 5-3). The logger is placed inside a thermal barrier, which protects the electronics from the hot atmosphere of the oven (see Figure 5-4). The logger system passes through the oven together with the product. After the run, the data is downloaded into analytical software. Using this software can help pinpoint problems.

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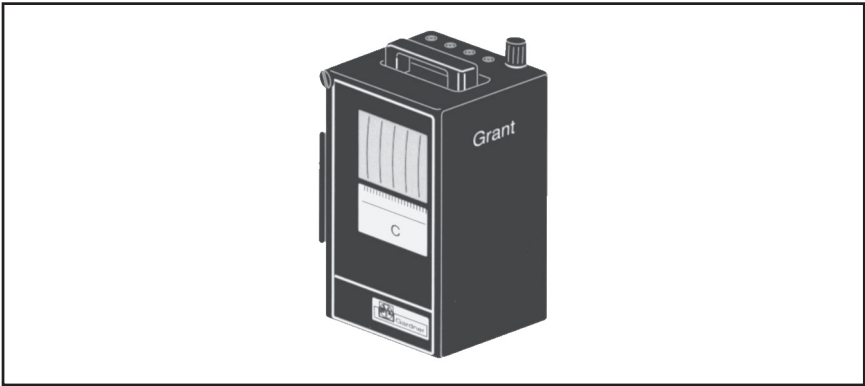


Figure 5-3. Grant recorder. (Courtesy Nordson Corporation)

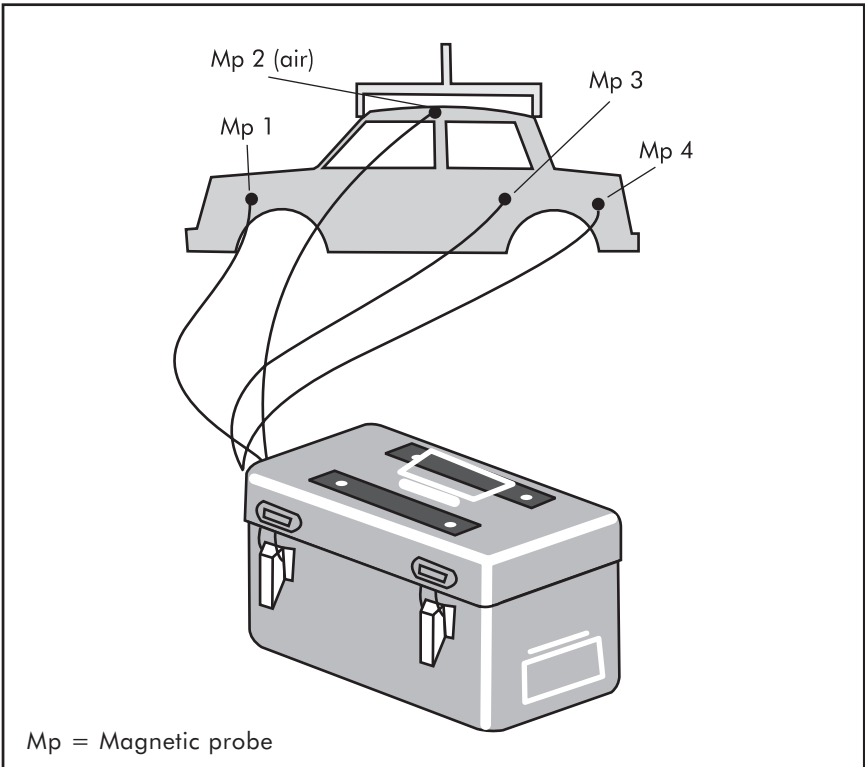


Figure 5-4. Protective thermal barrier. (Courtesy Nordson Corporation)

Pretreatment for Powder Coats

Virtually any product with a painted surface needs some form of pretreatment.

With powder as a topcoat, pretreatment should leave the raw part as clean as possible. A powder's performance is based directly on the pretreatment it receives. Needed testing relies on the pretreatment structure as the backbone of the topcoat.

Before beginning this chapter's discussion, a few definitions are in order:

- *Pretreatment* is the process of chemically cleaning and etching a substrate (part), before coating it (with wet or powder paint) to remove surface tension, soils, and contaminants.
- *Organic* soils are oils, waxes, mill oils, lubricants, cooling oils, and drawing compounds.
- *Inorganic* soils are rust (oxides) and dirt.

Other debris may cause pretreatment problems. This debris includes tape, gum, stickers, markers, and smut.

Keep in mind that solvent-based paints are more forgiving than powder formulations.

SOILS

Operations where soils can be introduced are:

- grinding,
- sawing,
- forming,
- milling,
- tapping,
- drilling,
- reaming,
- turning, and
- molding.

Types of Soils

Some soils are encountered on the raw material as it enters the production facility; others are introduced onto the part in the manufacturing operation. To supply the proper cleaning chemical, these soils' identities and their nature first must be determined. Consider:

- There are many types of soils and substrates. It is important to take soil and substrate audits to select the proper cleaner and conversion coating for the parts being treated. Other types of soils are shop dirt, smut, oil-metal chips, and drawing and release compounds.
- Petroleum-based soils are not water-based and are more difficult to clean than other contaminants (such as water-based soils).
- Often oils (such as cutting fluids) are introduced to reduce friction, protect against corrosion, provide anti-welding properties, and wash away chips. These types of soils tend to be water-based and, consequently, easier to clean than other contaminants such as a release compound from molds.
- Usually, inexpensive mill oils contain many impurities that can cause problems. These types of oils tend to dry and turn to varnish.
- Drawing and cutting oils are not always formulated for easy removal. While they may contain components with excellent lubricity, they are difficult to remove, especially after aging.

- Smut is difficult to remove. Smut is anything black or gray that can be wiped from the surface after a cleaner has removed the oils. These types of soils are metallic or mineral in nature and may include iron oxides, carbon or graphite deposits, and shop oils. Smut is typically embedded in the pores of the metal surface. An alkaline cleaner never completely removes smut. Like other metallic or mineral soil, smut must be removed with an acid. Even then, more of these soils may migrate to the surface. Because of the strong bond of the smut to the metal, this does not generally cause powder adhesion problems.
- Removal of petroleum-based soils is best done using high-alkaline cleaners.
- Silicone is harmful to powder-coat operations. It can be part of the release agents for molds. Silicone destroys the adhesion of the powder to the substrate. Parts per million of silicone can produce large problems. Carryover results once silicone is introduced into a pretreatment bath. Silicone is an inorganic polymer that can create “fisheyes” in powder, in addition to reducing adhesion. The elimination of silicones at the source is the only effective treatment option.
- Oils that are burned onto the surface via welding, or those that have been partially cured, take on a set. These soils need a substantially aggressive chemical to remove them.

Cleaning

Surface contaminants can range from difficult to relatively easy to remove.

Difficult soils. These soils include chlorinated lubricants; sulfurized lubricants; heavy-duty, rust-inhibiting compounds; honey oils; buffing compounds; stearates; die-cast release agents; and oxidized soils. Difficult soils tend to be heat sensitive. Naphthenic, paraffin, chlorinated-paraffin blends, or soils containing waxes are generally heat sensitive. Laser-cut edges are also difficult to clean.

Moderately difficult soils. These soils include fatty oils, waxy oils, heavy-duty hydraulic oils, mill oils, lapping compounds, and water-displacing rust inhibitors.

Relatively easy soils. These soils are soluble and include oil cutting fluids, synthetic cutting fluids, spindle oils, lightweight machine oils, mill oils, water-soluble oils, short-term inhibitors, and vanishing oils.

Removing soils. There are four steps to removing soils:

1. Determine the product (substrate) to be cleaned (pretreated).
2. Determine the material composition.
3. Define the surface profile.
4. Determine the cleaning method (sandblasting and/or chemical cleaning).

Soils and chemistries. Soils and surface preparation chemistries directly affect water consumption. Soils—such as drawing and stamping lubricants containing heat-sensitive waxes—require higher cleaning temperatures than other soils. Higher temperatures create more evaporation and water use than lower temperatures. Surface preparation chemistries, especially cleaners, must have dual functions. That is, they must remove, replace, or digest soils, and they must be free rinsing.

Cleaners with poor or excessive wetting can use increased volumes of water to provide adequate rinsing. The best option is to match the cleaners to the soils, or change the soils to be more compatible with the process and its controls.

Substrates. The composition, or chemistry, of a part's base metal is an important limiting factor in the choice of cleaners. The cleaner must be compatible with the metal. It is important to choose a cleaner that either does not attack the metal or that attacks the metal in a controllable way.

Many chemical suppliers and manufacturers make the common mistake of conducting incomplete base-metal audits when selecting a cleaner. Most aluminum and zinc alloys differ in alloy content and can vary widely in their ability to withstand alkaline or acidic cleaner attack. In some cases, a varied cleaner attack is unacceptable. To facilitate cleaner choice, substrates could be classified as follows:

- ferrous or iron bearing—cold-rolled steel, hot-rolled steel, stainless steel, and ferrous castings;

- nonferrous—aluminum, sheet, coil, castings, extrusions, zinc castings, galvanized, terneplate (a lead/tin alloy over steel), and zinc plated;
- yellow metals—copper and brass;
- mixed metals—combination of ferrous, nonferrous, and yellow metals; and
- composites—mixtures of metals with nonmetallic materials.

PRETREATMENT

Substrates to be painted generally include either steel or aluminum and some zinc. Zinc performs much like aluminum, so this discussion includes either steel or aluminum (or ferrous versus nonferrous metal).

Steels are alloys of iron and carbon in varying percentages. Generally, steels clean easily and accept a phosphate coating well. Aluminum is reactive to both alkaline and acidic solutions and does not accept a phosphate coating. If a conversion coating must be used, chrome can be used with good success, although successful powder coating does not require this. Iron or zinc-phosphate coatings work well with powder.

The *surface profile* is best described as being the actual surface to be coated. This surface area is best seen under a microscope. Paint can be applied to most profiles, however, profiles affect adhesion.

Many employees assume that pretreatment cleans every substrate. Nothing could be farther from the truth. Chemicals accomplish specific cleaning tasks depending on the make-up of the chemical. However, chemicals—for the most part—will not remove stickers, gum, marker writing, or oxide (rust). Fluorides can be added to acid cleaners to aid in some aluminum-oxide removal with large success.

When paint personnel work with parts, they should become accustomed to calling the part a substrate, because the surface of the substrate receives a topcoat. They should not assume that the surface does not contain an oxide; any oxide must be removed from the part before pretreatment. If rust is not removed, it grows

under the topcoat and ultimately forces itself through the topcoat. Topcoat materials should be applied to pretreated substrates. Again, chemical pretreatment over oxide is never a viable alternative. The pretreatment is designed for use on raw surfaces only.

All steel is originally hot rolled. After a furnace heats the slab, it passes through rolling mills, reducing it to the desired thickness. After it cools, it passes through another series of reducing mills. As steel is rolled, the grain hardens and becomes more brittle. Periodic softening, or annealing, between the rolling operations relieves the brittleness. Annealing involves reheating and re-cooling the metal. During this process, mill scale forms and must be removed. The hot rolling process also allows the steel to pick up impurities leading to mill scale.

Mill scale removal involves passing the steel through an acid pickling bath, and then oiling it to prevent rusting of the newly exposed surface. Called hot-rolled pickled and oiled, this steel is preferred for powder coating over plain hot-rolled steel (Gruss 1997).

Airless (Centrifugal Wheel) Blast (Ulrich 1993)

Introduced in the 1930s, centrifugal blast systems hurl abrasive material by centrifugal force. Machine systems available for various applications differ only in how the product is conveyed through the blast, the number and size of blast wheels required, and the type of blast media used. All centrifugal blast systems, whether for shop installation or portable use, have the same six basic components:

1. A blast enclosure is provided to contain the abrasive as it is thrown from the wheel and to prevent generated dust from escaping to surrounding areas.
2. As part of the system, there is a means of presenting the workpiece to the blast.
3. The heart of the system resides in the wheel or wheels, in whatever size and number are required for a specific application.
4. A means of recapturing and recirculating the spent abrasive is normal in all industrial systems.
5. To remove contaminant particles and abrasives too small to be effective, an airwash separator is included, which then returns the cleaned and usable abrasive to a storage hopper.

6. Essential is a dust collector that withdraws dust from the abrasive and ventilates and removes dust from the blast enclosure.

For applications in which the type and shape of parts and process requirements accommodate centrifugal blasting, the economy benefit has been proven many times over. Production rates are greatly increased and production costs significantly reduced. Airless blast-cleaning operations are far less labor intensive and far more energy efficient than airblasting. Uniformity of quality in the finished product is enhanced in automatic and environmentally clean operations.

Sandblasting and Pretreatment

Sandblasting is considered an alternative to pretreatment. Sandblasting is not a pretreatment and should not be looked at as such. It can rid the substrate of unwanted oxides and mill scale. Figure 6-1 shows a sandblast unit.

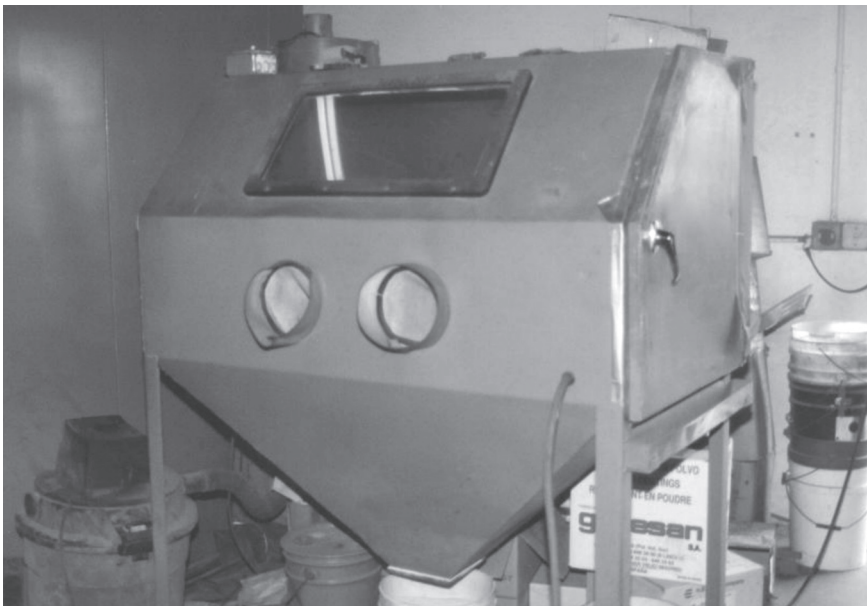


Figure 6-1. Typical shop sandblast unit.

With its efficiency and cost effectiveness, mechanical loose-grain abrasive blasting (sandblasting) is a growing worldwide industry. Hardness and grain size determine the abrasives' effectiveness on substrates or surfaces. Generally, a softer substrate, such as aluminum, dictates a softer, finer abrasive to achieve a required finish. Conversely, a tooled-steel substrate might tolerate a harder, coarser grit.

Blasting is increasingly used to remove coatings, corrosion, and rust from metals and other materials, replacing chemical solvents in many industrial settings. Innovations in abrasives and equipment are creating new opportunities for mechanical blasting, further expanding the loose-grain blasting market.

Abrasive Blasting

Abrasive blasting uses sand, steel shot, aluminum oxide, or glass bead that can pit or scratch even thick, hardened-steel substrates. The most common applications of hard, coarse grains are for the blast cleaning and surface preparation of steel structures. This applies to large-volume applications on roadway and railway bridges, structures of process-industry plants, storage tanks and pipelines, shipbuilding and railcar construction/repair, industrial construction, and manufacturing equipment maintenance. Finer grains are broadly used in industrial finishing applications, including paint stripping on vehicles where surface-finish quality is important. Coarse abrasives are normally larger than 0.0098 in. (249 μm) (retained on the U.S. sieve). For steel structure blasting, silica sand has been used extensively because of its ready availability and low purchase price. However, in recent years concerns about silicosis, a serious lung disease resulting from dust inhalation, has led to the banning of sand in many industrial areas.

Fine abrasives. Traditionally, fine abrasives are mainly glass beads and fused aluminum oxides that are normally smaller in size than 0.0059 in. (150 μm) (retained on the U.S. 100 sieve). Aluminum oxide is reclaimable and widely used in industrial cleaning and finishing settings. However, its hardness may lead to embedment problems or the need to blend it with glass beads to create a softer composite material. This adds to the already high cost

and slows down the cleaning process. Glass beads are softer and less expensive, applicable to a limited range of substrate hardnesses, and work slowly. Plastic media was developed to address niche opportunities in the market where no impairment of the substrate may be tolerated; but, plastics' excessive cost, slower speed, and potential dusting and static problems are disincentives to its use.

Sandblasting can change the substrate's surface profile. To make the change, determine whether the topcoat is presentable using this new profile. Some topcoats cover the millage that blasting opens and others magnify the profile for a poor-looking product. Sandblasting may introduce oils onto the substrate via the abrasive itself. This organic may be penetrated into the surface and unseen before a coating operation.

Sandblasting considerations. Some tips on effective sandblasting use include:

- Sandblasting improves adhesion, corrosion resistance, and appearance; fabricated, hot-rolled steel should be mechanically blasted before pretreating it with phosphate.
- Sandblasting must be uniform to ensure uniform adhesion and appearance characteristics.
- Generally, topcoats must be applied quickly after blasting to ensure that no oxidation occurs. (Most companies specify how long a part can wait without being primed or topcoated.)
- Sandblasting may be required on some substrates, but the substrate should also be pretreated for optimal performance of the topcoat.

While sandblasting is effective for surface cleaning and preparation, the industry is under scrutiny in worker health and environmental areas. Areas of particular concern center on the abrasives that remove toxic paints and coatings, but result in spent abrasive (which must be treated as hazardous waste). The dust generated during blasting is a potential worker-health hazard.

Regulatory responses to health and environmental concerns have heightened cost pressures and created market opportunities for more efficient surface cleaning and preparation products. As the use of sand in abrasive blasting has declined, other non-reclaimable substitutes have emerged, for example, inexpensive,

reasonably available slag materials. However, these materials generate spent abrasives that require proper disposal. Disposal costs and concerns about potential ongoing post-disposal liabilities are issues. Recently, certain slags have come under environmental and worker-safety scrutiny, due to their trace-metal content. Accordingly, media, such as steel shot and grit and garnet, emerged as substitutes for non-reclaimable abrasives. While reclaimability offsets the higher per-pound cost, these materials require powerful machines capable of delivering and reclaiming the heavier particles for application. Higher energy costs result. Users report other flaws, including media deterioration tied to environmental conditions, a limited range of applicable substrates, undesirable surface embedment, and, most importantly, a low cleaning speed.

Loose-grain blasters. Loose-grain blasters ideally need an abrasive formulation that is reasonably priced, reclaimable, and that can prepare substrates to a high-performance surface finish with exceptional speed. No available abrasive provides this complete set of desired characteristics. In the case of media that are reclaimable for many cycles, such as steel grit and shot, the granules are highly malleable, resulting in a slow cleaning speed. In the case of abrasives that are moderately reclaimable, such as aluminum oxide and garnet, the hardness of the granules results in a rounding action upon impact, leading to a significantly slower action after the initial use. In addition, they often embed in the blasted surface. Abrasives that are not reclaimable, such as sand and coal slag, are brittle and dusty, and provide slow-to-moderate cleaning rates.

Industry demands efficiency, quality, and consistency in its finishing operations. The desired result of impact relies on balancing several variables, including the nozzle diameter, distance from the work surface, angle of application, and the force (air pressure) of delivery. The final and most important element of control lies in the impact media's size and quality.

Impact blasting is one alternative for surface treatment application. Selection of the proper media maximizes its proven efficiency. Equipment, ranging from manual to fully automatic, supports the growing market for impact-blasting technology. The required capital investment pays immediate dividends. However, operator training, direct labor, supervision, energy consumption,

waste disposal, and maintenance must be taken into consideration. Impact blasting, in conjunction with proper pretreatment, provides outstanding results.

Chemical Surface Preparation

Chemical surface preparation in an application is closely related to the nature of the surface being cleaned and the surface's contaminants. Most surfaces that are powder coated after cleaning are of galvanized steel, steel, or aluminum. Since not all chemical-type preparations are applicable to each material, the preparation depends on the substrate material.

Cleaning Galvanized Steel

Alkaline cleaners for galvanized steel usually blend mild alkaline salts. These salts do not damage zinc surfaces. In some cases, free caustic soda may be present in the cleaner to remove difficult soils or to provide a desired etch. Power spray or the immersion process applies these cleaners.

In the power-spray method, parts are suspended in a tunnel while the cleaning solution is pumped from a holding tank and sprayed under pressure onto the parts. The cleaning solution is then continuously recirculated. Spray pressures range from 4–40 psi (28–276 kPa).

In the immersion method, parts to be cleaned are simply immersed in a solution of the cleaner contained in a mild steel or stainless-steel tank. Hand wiping with a cloth or sponge derives additional benefit from the physical act of removing the soil from the surface, with the cleaner helping to solubilize the soils.

Alkaline cleaners usually are applied to galvanized zinc surfaces in two stages: the cleaning stage and a water rinse. The parts to be cleaned usually are conveyed through the stages after suitable exposure produces adequate cleaning. The chemicals in the baths usually maintain a temperature between 80–200° F (27–93° C). Typically, the temperature is 120–150° F (49–66° C) for immersion.

Because steel surfaces are resistant to aqueous alkaline-cleaner solution attack, a variety of alkaline cleaners can be formulated for each application. In general, combinations of phosphates, silicates, and carbonates with varying amounts of caustics, may be encountered. In addition, sequestering or cleaning agents, solvent, solvent couplers, dispersants, and one or more surfactants, non-ionic or anionic, are used.

Acid cleaners are usually not used to clean galvanized steel. Of those acid cleaners, mild acidic salts that are not too corrosive to the zinc surface are the most common. It should be noted that specialty acid cleaners are designed to remove white corrosion from the galvanized surface.

Mineral acids, such as sulfuric or hydrochloric acid, are commonly used to remove rust, heat scale, and corrosion products from steel. Organic acids and phosphoric acid, together with solvents, coupling solvent, and surfactants remove soils, red rust, and other types of corrosion.

Functions of the Washer

The washer has four functions:

1. It cleans the substrate of soils.
2. It etches the metal or provides a conversion coating for paint adherence.
3. It seal rinses the substrate.
4. It rinses residual contamination.

The most common washer systems have three or five stages. (Of course, they can have any number of stages.) A three-stage washer system generally is found on lower-volume production lines and in small shops. Properly maintained, a three-stage washer performs well. A five-stage washer system provides superior pre-treatment.

The iron phosphatizing of steel serves three purposes. First, the process creates a porous structure thus increasing the substrate profile. Therefore, powder-coating adhesion improves. Second, iron phosphatizing provides a barrier of low conductivity, thereby reducing the corrosion under the powder coating. Third,

it creates a chemical bond to the metal surface, preventing corrosion from undercutting the powder coating.

Iron phosphatizing involves cleaning the substrate, pickling or acid etching the metal, and raising the pH at the metal surface so a coating forms on the etched metal.

The iron phosphate conversion coating includes the following:

- a phosphate source to form the phosphate coating;
- an acid source to etch the surface of the metal to begin the process;
- an accelerator to help form the coating; and
- buffering agents to control water hardness and maintain pH.

PHOSPHATE COATINGS

Phosphate coatings are produced on ferrous and nonferrous metal surfaces. They are composed of phosphate crystals of iron, zinc, or manganese. The inorganic coatings produced on metal surfaces retard corrosion and promote better paint bonding. Phosphate coatings are formed after cleaning in a combination bath known as a cleaner-phosphate.

The finishing industry generally uses phosphate coatings to:

- provide a base for bonding organic finishes such as paints, lacquers, plastics, rubber, adhesives, and powder coatings;
- provide a base for oils, waxes, and rust preventives to reduce corrosion;
- provide a base for lubrication on bearing surfaces to reduce friction; and
- aid in drawing and forming metals.

When the metal meets the phosphatizing solution, pickling occurs. This pickling results in a reduction of acid concentration at the liquid-metal interface. At this point, iron is dissolved, hydrogen is evolved, and a phosphate coating is deposited. Should the solution contain additional metal ions such as zinc or manganese, phosphate coatings of these ions also are deposited.

Accelerators such as nitrite, nitrate, chlorate, peroxide, or special organic chemicals may be added to the phosphate to increase

the rate of coating deposition. The pH is dependent on the chemistry in use.

In general, iron phosphate coating weights of 0.0009–0.0025 oz (25–71 mg) and zinc phosphate coating weights of 0.0035–0.0106 oz (99–301 mg) are commonly accepted as bases for paint bonding.

A phosphate coating retards corrosion creep or spread.

Iron Phosphatizing

Iron phosphatizing is the most widely used conversion coating. Iron phosphate benefits include:

- low cost,
- wide parameters,
- application is easy to maintain,
- disposal is not complicated,
- it works well with powder on many metals, and
- it is an industry standard for powder.

Iron phosphatizing promotes the adhesion of powder and prevents short-term corrosion. It also maximizes powder life.

Iron phosphate coatings are usually derived from solutions containing little iron. They are produced on ferrous metals through the combination of acid phosphate salts, free phosphoric acid, and accelerators. For nonferrous metals, such as aluminum and zinc, a micro-etched surface and a combination alloy phosphate are produced in place of a normal phosphate coating in the range of 0.001–0.002 oz/ft² (40–70 mg/m²).

Operating pH varies with the type of phosphate compound. Some favor a pH in the range of 3.5–5.0; others a pH in the range of 4.8–6.0. It is more economical to use pH-adjustable acid concentrate than to change or add phosphate compound. In most instances, the pH rises in operation.

For a cleaner and iron phosphate combination, the cleaning ability of the chemical formulation is critical. No quality phosphatizing takes place until the surface is sufficiently void of organic soils. Frequently, operators and managers stress coating weights and salt-spray requirements in iron phosphate operations for three-stage washer systems when they should be more focused on soil control, cleaning ability, and system upkeep.

Lines or systems treating both ferrous and nonferrous metals through an iron phosphate system are generally faced with a major compromise as maximal salt-spray performance produces a varied effect on the metals. Users should evaluate and test the substrates before equipment installation. For high corrosion protection, consider two pretreatment lines.

Zinc Phosphatizing

Zinc phosphatizing gives superior performance when compared to iron phosphatizing.

A zinc phosphate coating is crystalline and extremely adherent to the substrate. A zinc phosphate processing solution produces a good quality coating and an outstanding paint base on aluminum.

In the power-spray method, parts are suspended in a tunnel. The coatings solution is pumped from a holding tank and sprayed on the parts. The coating solution is continuously recirculated. The chemical is siphoned into the steam at the nozzle with a specialized spray application that uses a steam generator. With the immersion application, the parts are immersed in the coating solution contained in a mild steel or stainless steel tank. The hand-wiping method has limited use in conversion coating technology.

Five stages of operation usually are required to create a zinc phosphate coating on aluminum. The temperature of the solution is between 108–160° F (42–71° C) for spray and 120–200° F (49–93° C) for immersion. Coating weights of 0.002–0.007 oz/ft² (50–200 mg/m²) are usual. Times of 1–3 minutes, by spray, and 2–5 minutes, by immersion, are needed. Solutions having a concentration of 4–6% by volume are applied at spray pressures of 5–10 psi (35–69 kPa).

To produce a conversion coating on aluminum, users can apply a zinc-phosphate processing solution. While it is a good paint base, insoluble sludge is produced. This sludge can deposit on plate coils and decrease heat transfer efficiency. It can plug the nozzles and piping in a spray application. It is, therefore, necessary to clean the zinc phosphate coating stage in the processing line at least annually.

To produce a zinc-phosphate conversion coating on steel surfaces, different proprietary compositions can be used. These products are acid solutions containing zinc; dihydrogen phosphate in aqueous

solution; one or more acceleration agents, typically zinc nitrate, with or without tankside additions of nitrite; and one or more modifying agents, grain-refining agents, or coating weight-control agents, etc.

To produce a zinc-phosphate coating, proprietary zinc-phosphate coating compositions can be brushed on clean steel surfaces. The surface must be cleaned before the application of the conversion coating. The process involves the following:

1. The brush-on treatment is applied.
2. The coating is allowed to develop.
3. The part is rinsed with fresh tap water and dried.

The brush-on treatment produces an acceptable coating in 2–5 minutes. Compositions are typically applied unheated to a surface at room temperature. Since these are mostly proprietary formulations, the manufacturer's instructions must be followed to determine concentration. It is technically possible to produce a zinc-phosphate coating on steel by applying the coating product through a steam gun, although this method of application is not used.

Proprietary zinc-phosphate coating compositions are available for immersion application. As with the iron phosphate processes, power-spray washer application accounts for the largest proportion of paint-base zinc-phosphate treatment processing. Depending on many factors, including the nature and amount of soil, the rinsing and draining geometry of the part, and the required quality levels, as few as five stages and as many as nine stages may be needed.

Zinc-phosphate treatments can be accelerated to operate and produce quality paint-base coatings at temperatures as low as 80–90° F (27–32° C). Zinc-phosphate treatments usually are operated at 3–6% concentrations, or at a typical titration as low as 0.3 oz (10 mL) and as high as 0.8 oz (25 mL), depending upon the quality requirement and particular proprietary treatment.

RINSING

Rinsing tends to be taken for granted because it is such an apparently simple process involving “only water.” However, water is actually a complex chemical.

Rinsing is a critical step in powder-coat pretreatment because a part is no cleaner than the quality of the rinse water used. Just as surface cleanliness is a fundamental prerequisite in quality painting, the rinse is critical in pretreatment. Rinses remove prior-applied chemicals and residual contamination remaining on the part. They help neutralize chemicals or contaminants that interfere with adhesive forces. These forces bond paint to a surface, whether the surface is metal, plastic, or wood.

Rinsing with city water usually leaves total dissolved solids (TDS) on the substrate or part.

Various processes clean substrate surfaces. These cleaning processes are aqueous, solvent, abrasive, flammable, and cryogenic. The optimum process depends on many parameters. These include the type of material being finished, the size and shape of the object, the end-use environment, the desired life expectancy of the applied coating, and the coating type.

Aqueous cleaning, or water cleaning, is by far the most common. Aqueous systems are often power-spray washers. These washers include four basic processes: cleaning, conversion coating, sealing, and rinsing. The function of this cleaning is to remove soils, oils, and other contaminants. The purpose of the conversion coating is to alter the surface chemically with a material, such as a phosphate, to improve corrosion resistance and paint bonding. The goal of sealing is to finesse the conversion coating and give the surface the proper pH for accepting paint. The task of rinsing is to remove dragout contaminants between stages. They should also be removed after the last chemical stage.

Each of the four aqueous processes is equally vital. Each process can be compared to each of the four legs of a table. Remove any leg, and the table falls. Remove any aqueous surface preparation process, and no optimal paint bonding results.

Water's strong hydrogen bonding gives it a high surface tension. Floating a needle on the surface of water is a great way to demonstrate water's surface tension. The hydrogen bonding at the surface prevents the needle from sinking, even though the needle is approximately seven times the water's density.

Hydrogen bonding is responsible for many of water's properties, such as surface tension and viscosity. Both surface tension and viscosity decrease as the temperature of the water increases.

This is because increased molecular motion decreases the strength of the hydrogen bond.

The chemical structure of water makes it an ideal solvent. Pure water has low conductivity. However, as water's ionic content increases, its conductivity increases. Therefore, conductivity is a good measure of the purity, or the amount of dissolved solids, in a water sample.

A majority of finishers make several mistakes leading to the overuse of water and an increase in pretreatment chemistry costs. A list of common mistakes of finishers follows:

- They use high-temperature cleaners that not only shorten chemistry life, but also increase evaporation, water use, and maintenance and energy costs.
- They use poor-quality cleaners and conversion-coating chemistries that lead to frequent dumping and recharging. This increases water use and places a greater-than-necessary burden on pretreatment.
- They do not use water meters on individual process stages. This leads to an overuse of rinse water.
- They control rinse-water quality visually, rather than by TDS and pH readings. This results in ineffective rinsing or water waste.
- They hang parts improperly and use poorly designed hangers, causing drag-out, drainage, and water-cupping problems.
- They have systems with inadequate and undersized tank volumes and incorrect drain-vestibule lengths that create water and chemical waste. Thus, there is a subsequent decrease in powder performance.

Water Quality

A part is no cleaner than the quality of the rinse water used. The purpose of effective rinsing may be any or all of the following factors:

- to flush remaining wetted soils from the substrate;
- to neutralize or dilute remaining alkalinity after the cleaner stages;

- to maintain a wet substrate between stages;
- to flush the non-adherent phosphate or conversion coating from the substrate; and
- to cleanse excess water hardness and salts before dry off.

Proper and adequate rinsing is critical in powder-surface preparation when an accelerated corrosion specification is required. The essential factors affecting sound rinsing are:

- original water quality,
- water volume,
- immersion or spray,
- contact with part,
- part configuration, and
- solution contact time.

Initial raw-water quality varies from municipality to municipality. The existing water should be analyzed for unexpected or changing water conditions throughout the year. The simple routine of municipalities flushing out their fire hydrants may introduce enough change in the incoming water to stop the operation.

Consider the very nature of water before considering water to be a pure and effective rinse for parts. In its pure state, water is one of the most aggressive solvents known. Called the universal solvent, water, to a certain degree, dissolves everything exposed to it for a sufficient enough period of time. Pure water has a high-energy stage, and like everything in nature, it tends to achieve energy equilibrium with its surroundings. It attempts to dissolve the quantity of material required to reach saturation (the point when no higher level of solids can be dissolved). Contaminants found in water include: atmospheric gases, minerals, organic materials from the earth (some naturally occurring, others man-made), and materials used to transport or store water.

The hydrologic cycle, as shown in Figure 6-2, illustrates the process of contamination and natural purification. Water evaporates from surface supplies and transpires from vegetation. The evaporated water then condenses in the cooler air of the atmosphere where it dissolves gases such as carbon dioxide, and natural and industrial emissions, such as nitric and sulfuric oxides, as well as carbon monoxide. Typical rainwater has a pH of 5–7. These

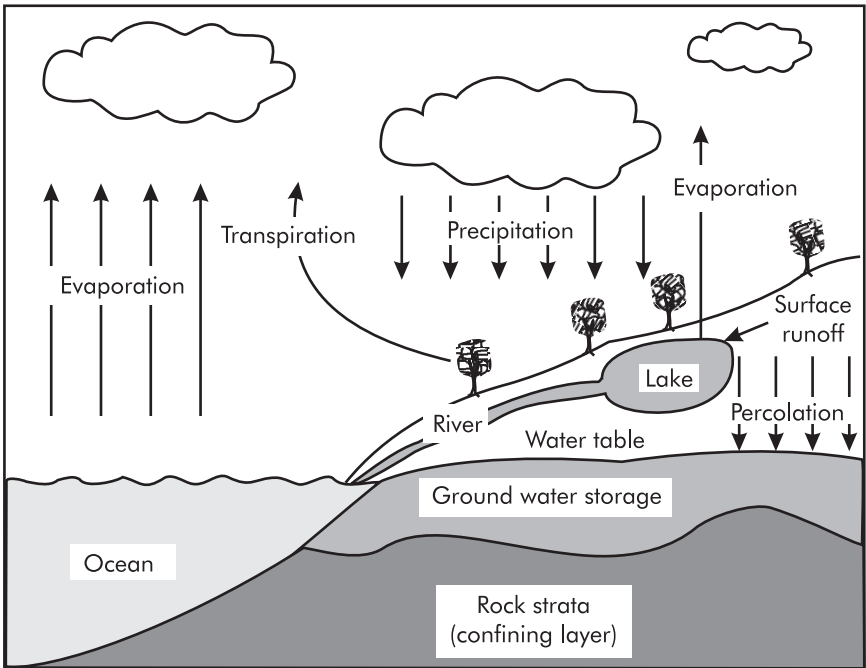


Figure 6-2. Hydrologic cycle.

dissolved gases usually result in a mildly acidic condition, what is today called *acid rain*, possibly having a pH as low as 4.5.

Atmospheric moisture condenses on nuclei such as dust particles and eventually returns to the earth's surface as rain, snow, sleet, or other precipitation. As the precipitation nears the ground, it picks up many additional contaminants—airborne particulate, spores, bacteria, and emissions from countless other sources. Most precipitation falls into the ocean, and some evaporates before reaching the surface of the earth. The precipitation reaching land replenishes groundwater aquifers and surface water supplies. This process substantially filters the water percolating down through the porous upper crust of the earth, and most particulate matter is removed. The bacterial activity in the soil consumes much of the organic contamination and a relatively clean, mildly acidic solution remains. This acidic condition allows the water to dis-

solve many minerals, especially limestone, which contributes calcium. Other geologic formations contribute magnesium, iron, sulfates, and chlorides. The addition of these minerals usually raises the pH of the water to a range of 7–8.5. This mineral-bearing water is stored in natural underground formations, called *aquifers*. They are well-water sources for homes, industries, and municipalities.

Surface waters—such as rivers, lakes, and reservoirs—typically contain less mineral contamination, but hold higher levels of organic and particulate, as the water does not pass through the earth's top and lower soils, gravel, and rocks.

Another difficulty affecting water purity is bacterial contamination and the control over bacterial growth. Water is a necessary medium for bacterial growth because it carries nutrients, and its thermal stability provides a controlled environment. Water supports bacteria growth with even the most minute nutrient sources available.

What is Spot-free?

The following data helps the decision process if a spot-free rinse is required. It also should help determine which system best generates spot-free, or pure, water.

First, what are spots? *Spotting* is the residue that dissolved solids leave when a water droplet evaporates. The higher the total dissolved solids (TDS) in the water, the worse the spotting. As water stops *sheeting* (or running) off of a surface, it forms little half-moon shapes in a process commonly referred to as *beading up*. (It technically is the formation of a *meniscus*, having to do with surface tension and wetting ability.) As the bubble evaporates, the solids (which do not evaporate) settle out in the shape of the bottom of the bubble. Since many solids are actually salts, it becomes obvious why soft water often spots more than hard water, since softening merely replaces metallic ions with sodium (salt) ions. This is generally why water softening alone probably should not be used for pretreatment in powder operations. The sodium ions on the parts, or the spotting received from the sodium ions, are not needed. Check with a chemical supplier to get a water analysis to confirm water softness. At about 40–50 ppm

(parts per million) spots appear on dark parts. At about 75 ppm, spotting appears on glass and chrome, and at about 150 ppm, spotting appears on all surfaces.

What is the normal TDS of water? According to some recent trade journals, the average is between 250–300 ppm TDS in the United States. At this rate, if a spot-free part is required, treatment is needed.

There are two basic methods of removing solids from water, *deionization* (DI) and *reverse osmosis* (RO). The deionization process can be compared to a water softener where water flows through a resin bed. The resin bed absorbs the solids. A service company exchanges the exhausted resin bed with a fresh tank and charges a fee for each exchange. In an RO unit, the water is forced through a membrane, filtering out the solids. There are advantages and disadvantages to both DI and RO, as shown in Table 6-1.

Water Conductivity

When discussing conductivity, the quality of the incoming raw water is important. Manufacturers should seek the opinion of an independent source or a chemical pretreatment vendor who analyzes water to explain why its constituents behave in a positive or negative way. In gaining this understanding, there are three ways to treat the incoming water:

1. softening,
2. reverse osmosis (RO), and
3. deionization (DI).

Softening

Water softening exchanges high amounts of calcium, magnesium, or other minerals found in water for sodium. A common industrial-sized softener can remove those water constituents that lead to scale build-up in the nozzles, tank walls, and heating apparatus found in heated washers. Sodium is more soluble and less likely to produce hard scale than the minerals it replaces. A

Table 6-1. Comparison of deionization and reverse osmosis water purification

Deionization	Reverse Osmosis
Minerals are removed by ion exchange media.	Uses a pump to force water through a membrane to “filter” out dissolved minerals.
99.999% removal of TDS yielding consistent quality regardless of input.	98–99% removal of TDS, depending on the particular salts that are present: final quality depends on the raw quality.
pH 6.5 weak base, 5–9 strong base.	pH usually slightly acidic.
Needs no storage tank.	Needs large storage tank.
Produces 1 gal (3.8 L) of good water for every 1 gal (3.8 L) of water used. No waste.	Will reject (discharge to sewer) 1 gal (3.8 L) of water for every 2–3 gal (7.6–11.4 L) of good water produced.
Tanks need to be monitored and exchanged as needed.	Uses no chemicals in ordinary use. The required water softener will only use salt water to regenerate.
Needs little or no maintenance.	Needs maintenance and monitoring.
Flow is steady through a wide temperature range. Requires no water heater to operate.	Membrane flow rate based on 77° F (25° C). Loses 1.5% of flow for every degree of temperature drop (at 47° F [8° C] 45% of rated flow is lost).
Will accept hard-chlorinated water.	Water must be softened, dechlorinated, and filtered to prevent premature failure of the membrane.
No major replacement costs.	Membrane life is fairly short, usually 3–5 years. Expensive membrane is easily ruined if not properly maintained.
Requires very little space; has a small footprint.	Storage of water softener and carbon filter requires a great deal of space.
Operating cost typically is between \$14–26 per 1,000 gal (3,785 L), depending on mineral content.	Operating cost runs \$7–10 per 1,000 gal (3,785 L).
High iron or sodium content water areas require no pretreatment.	Usually requires an activated carbon pre-filter to remove chlorine and other organics, which could ruin the membranes, and a softener to remove hardness.

manufacturing facility with hard water that is using alkaline cleaning baths is a good candidate for softened water typically in a hardness range of 15 gr/gal (256 mg/L). However, the exchange of calcium and magnesium for sodium raises the TDS level. This rise in TDS is typically due to inadequate or incomplete back-flushing when removing excess sodium. Make sure the softener is well designed, well sized, and well maintained.

It is important to note that a softener is not recommended for the rinse before and after the phosphate stage. It is not recommended for final seal-rinse stages either, because the remaining dissolved solids are more soluble and conducive to corrosion than the original hard-water minerals.

Softening should be reserved for RO units only.

Softeners should use a high-quality salt (either rock or pellet style). If the salt-brine container is too small to accommodate the amount of salt that is needed, fill the container approximately half full when salt is needed. This way, water does not reach the lid and cause overflow during regeneration. The extra space in brine tanks assures that the tanks are relatively safe from overflow.

Reverse Osmosis

Reverse osmosis (RO) is a form of water conditioning used to develop high-quality water for finishing. Basically, in RO, water is passed between semipermeable membranes. These membranes remove hardness, minerals, and other constituents. RO systems are most desirable when large volumes of an improved water source are necessary. A blend of RO and raw city water can improve the water for active chemical stages.

RO systems are generally more expensive to install than DI systems, but are cheaper to maintain.

Deionizing

Deionizing water relies on reactions. The first reaction uses a cation exchange regenerated with an acid to remove metal ions and replace them with hydrogen ions. The second reaction is an

anion exchange to remove the acids produced. This reaction is regenerated with an alkaline solution.

By definition, DI water has the *cations* (positive ions) and *anion* (negative ions) removed and is water in the pure state. However, this is untrue. DI water has usually been run through cation and anion exchangers. Most cation exchangers work more efficiently than anion exchangers do. This means DI water contains a small percentage of excess anions and, therefore, can be slightly acidic.

DI water is the most frequently used source of high-quality water in the final rinse stages of surface preparation. This step removes unreacted deposits and leaves the substrate virtually free of dissolved and undissolved solids.

All naturally occurring water contains dissolved mineral salts. In solution, salts separate into positively charged cations and negatively charged anions. DI can reduce the amounts of these ions to low levels with ion exchange.

Cation-exchange resin removes cations. It replaces sodium, calcium, magnesium, and other cations with hydrogen ions (OH). The exchange produces acids, which anion exchange resin removes or neutralizes.

Weak and strong base are two types of anion resins used for DI. Weak-base resins absorb strong acids, while strong-base resins exchange chloride, sulfate, and alkaline anions for OH. The hydrogen ions from the cation-exchange process combine with the hydroxide ions from the anion-exchange process to form water (H₂O or H₂O).

Because the deionization process is highly effective, the resistance of water to electric current (in ohm/cm) is the measurement of the water quality. Deionized water quality depends on a variety of factors, including raw water composition, ion-exchange resin types and quantities, and the number of resin tanks in the system.

Two-bed deionizers use separate tanks, one containing cation resin, and the other containing anion resin, as shown in Figure 6-3. A two-bed, weak-base deionizer typically produces water with an electrical resistance of about 50,000 ohm/cm. A two-bed strong-base deionizer typically produces water with electrical resistance of about 200,000 ohm/cm.

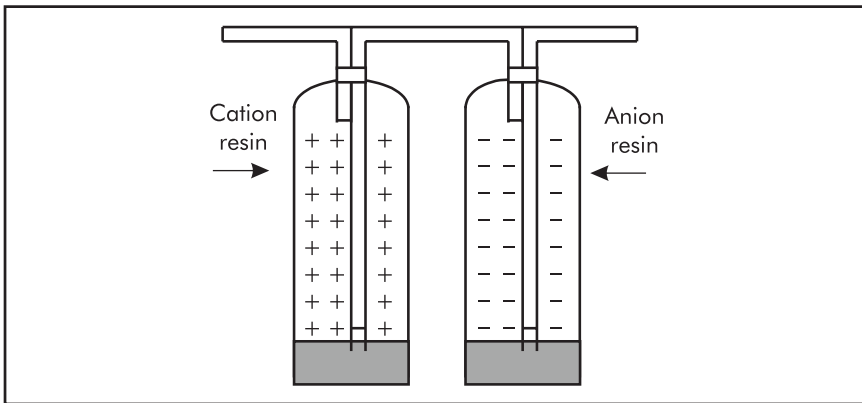


Figure 6-3. Two-bed deionizer.

The resins need regeneration when they no longer produce the desired water quality. In the case of a two-bed deionizer, the cation tank is backwashed for 5–10 minutes, then washed with a 6% solution of hydrochloric acid. Then, the anion tank is backwashed and washed with a 5% solution of sodium hydroxide. After rinsing residual chemicals from each tank, water flows through both tanks to drain until the water reaches the desired quality.

A mixed-bed deionizer is where cation and anion resins are mixed in a single tank, as shown in Figure 6-4. The mixed resins act like a series of alternating cation- and anion-exchange tanks to produce high-quality water. A mixed-bed deionizer typically produces water with greater than 10,000,000 ohm/cm resistance, which is equivalent to less than 0.0029 gr/gal (0.05 mg/L) of sodium chloride.

The resins must be separated before regeneration in a mixed-bed deionizer. After regeneration and rinsing, the resins must be remixed using air, before returning to service.

Although the process is simple in concept, there are various complications in the application. These variables are in raw-water composition, treated-water quality, resin selection, chemical dosages, and control-system requirements.

Water Purity

The word *pure* has different meanings when water is involved. Some people and some water departments claim water is pure

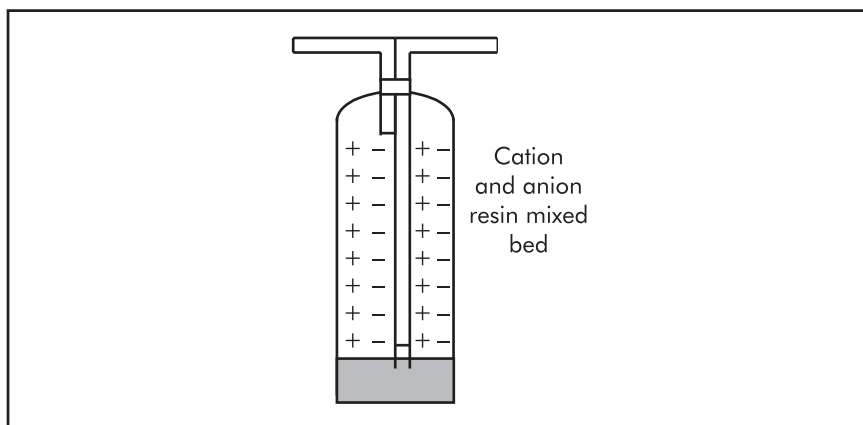


Figure 6-4. Mixed-bed deionizer.

when it is free of objectionable tastes, odors, suspended matter, and colors, and is safe to take internally. This kind of pure water may contain dissolved minerals in varying amounts, including the hardness minerals. To the medical profession, pure water has these characteristics, but it must be free of disease-producing organisms. It must be sterile. To chemists, pure water is low in dissolved mineral content, often extremely low, yet such water may or may not contain organic and other matter.

Filtration and/or chlorinating processes render many public water supplies pure. The medical profession relies upon distillation as the process for producing sterile water. Chemists may employ distillation, or they may use the DI process.

Distilled Water

Boiling water and then condensing the steam back into it distills water. *Distillation* uses physical heat to separate water from its organic and mineral content. Thus, separation is not 100% as some mineral content is carried over with the steam. The U.S. Pharmacopoeia specifies that distilled water contains a maximum of 5.0 ppm of TDS. It can contain less, and often does. Triple distilled water may contain as little as 0.5 ppm of TDS. Special distillation procedures can produce water purer than this.

Ion Exchange

Ion exchange is the substitution of one kind of positive ion for another or the substitution of one kind of negative ion for another. This is also called *ion trade*. A clearer definition might be: ion exchange is the reversible interchange of ions of similar electrical charge between a solution and a solid insoluble body in contact with the solution. The solid insoluble body is called an *ion exchanger*, or *ion trader*. The most common ion exchanger is soil.

Water softening and water deionization are both methods of ion exchange. Both make use of synthetic resins. Softening uses one resin; deionization employs two resins. A resin used in deionization is also used in the water softening process. In water softening, there is an exchange of sodium ions on and within the regenerated beads of resin for calcium, magnesium, and soluble iron ions in the raw water. Calcium, magnesium, and soluble iron ions are removed from the water, while the sodium ions go into the water in an equivalent amount. There is an increase in the quantity of dissolved solids in the softening process. In deionization, there is reduction, sometimes virtually complete, in the total dissolved solids content. Perhaps deionization is called an ion-removal process because, although ion exchange is the principle involved, the result is ion removal. Deionized water is, as expected, also “soft” water in the sense that the hardness minerals, among others, are removed during the deionization process.

Some ions have a positive electrical charge; some have a negative electrical charge. Sodium ions react with chlorine atoms to form sodium chloride (table salt). When table salt dissolves in water, it ionizes. The sodium ion gives up an electron and becomes a sodium ion with a positive electrical charge. The chlorine atom gains an electron and becomes a chloride ion with a negative electrical charge. Ions, then, are electrically charged derivatives of atoms or groups of atoms but are neither atoms nor molecules. Ions of nonmetals generally have a negative charge. Hydrogen, a gas, has either a positive or a negative electrical charge, depending on the chemical compound of which it is a component. Ions of only one type of charge cannot exist alone. A positive ion must have a negative ion in its immediate vicinity, and vice versa.

An ion exchanger must be insoluble in water or solution. In addition, it must have enough space between its large molecules, or exchange sites, to allow small ions to move freely in and out of the solid. This solid is sponge-like in structure. Its exchange sites must have either a positive or negative electrical charge, and small ions of opposite charge are either present or provided in some way. Electrical force holds the ions to the exchange sites. Some ions have one unit of electrical charge each (sodium), some have two each (calcium), and some have three (aluminum). It is the numbers of electrical charges, not the number of ions, that must stay constant in and on an exchange-resin bead.

Measuring specific resistance. The fewer chemicals dissolved in water, the more the water resists the passage of an electric current through it. This *specific resistance* is measurable in ohms, the unit of electrical resistance. Natural waters have a specific resistance in the 1,000–5,000 ohms range. Deionized water may have a specific resistance indicated as 50,000 ohms or higher. Ultra-pure water has a specific resistance in millions of ohms. Ohmmeters designed to read ohms in millions are calibrated in meg-ohms (meg means million). Six meg-ohms indicates six million ohms of specific resistance. Theoretically, pure water has a specific resistance of 18,000,000 ohms when measured at 77° F (25° C). This value changes as the water temperature changes; increasing as the temperature increases.

Conductance. *Specific conductance* is the ability of water to carry an electric current. The greater the mineral content of the water, or solution, the higher its specific conductance. When specific resistance is high, or conversely, when specific conductance is low, the unit of measurement is micro-mho (micro means millionth). A micro-mho (μmho) is equal to 1,000,000 divided by ohms. Deionized water with a conductance of 1.0 μmho has a specific resistance of 1,000,000 ohms. This is about $\frac{1}{2}$ of 1 ppm of sodium chloride. Pure water has a conductance of 0.055 $\mu\text{mho/cm}$ at 77° F (25° C).

A meter, either battery or electric-current operated, indicates the conductivity (specific conductance) in ppm of TDS as calcium carbonate or as sodium chloride. Some meters are calibrated to read in ohms and in meg-ohms. Meters work in conjunction with

flow cells. Flow cells are positioned in the effluent stream and have two electrodes. Wires connect the cells to the meters.

A monitoring light is an indicating light operated with a flow cell positioned in the effluent piping. A monitoring light may be coupled with a bell to create a bell alarm.

The *cut-off* point is the point where the deionized water quality is no longer desirable for use. This cut-off point varies according to the user's requirements. It can range from 25,000 ohms (25 K) up to 1,000,000 ohms (1,000 K), or even higher. Some monitoring systems have adjustable cut-off points; some have fixed points. In some cases, the monitoring system is coupled with special valves. When the cut-off point is reached, the valves close, thus shutting off the water flow to the deionizing equipment.

Typically, the TDS approximates 65% of the specific conductance. For highly mineralized waters and highly colored waters, the TDS is more than 65%. For water containing large amounts of acid, caustic soda, or sodium chloride, the TDS is less than 65%.

Mineral-free Water

Either distillation or deionization produces mineral-free water. It is most often found in advertising as a substitute term for distilled or deionized water. Both distilled water and deionized water are "demineralized water," but the terms "demineralization" and "demineralized water" are often used in place of "deionization" and "deionized water." Deionization is the more technical term, and demineralization the more popular expression.

In many areas of application, distilled and deionized water compete with each other based on quality, convenience, and cost. Distillation removes the water from its mineral content, and deionization removes the mineral content from the water. Distillation kills organic matter; deionization does not remove organic matter except incidentally through filtration. Distillation uses physical means (heat); deionization removes only ionized substances. In many instances, deionization produces purer and cheaper water than does distillation. In addition, it can produce this high-quality water within a pressure system, at ordinary temperatures, and make it available through a pressure line. The big-

gest advantage of deionization is the low cost of production, except where TDS is high, as in brackish and sea water. It is simple, efficient, economical, and the modern way to produce chemically pure water.

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Pretreatment Washer System Design and Construction

WASH SYSTEMS

Generally, pretreatment systems are designed to clean and etch a metal surface. The washer cleans the surface and etches a profile into the part's metal. Paint adheres to the profile. Pretreatment takes place through several stages and each stage performs a function. Written procedures and specifications are determined by powder coating and cleaning chemical vendors. This gives users crucial information about proper part pretreatment during various stages.

Power-wash systems are designed with nozzle-and-riser configurations. The *risers* are the piping materials that feed the nozzles. Generally, risers are spaced at 12 in. (30.5 cm) increments. The nozzles also are spaced at 12 in. (30.5 cm) increments. This pattern changes, depending on the substrate profile.

Drains

Drains allow for dripping and chemical runoff prior to the next stage. They are designed to be located between stages. Generally,

a drain zone must be as long as the longest part being pretreated, allowing runoff to drain back into its most recent stage. If the drain zone is not as long or longer than the part, then carryover to the next stage results.

Carryover can contaminate rinse waters, neutralize chemicals, and create overflow stages, causing unnecessary chemical makeup and improper cleaning. Generally, most drains are split to run 50% of the drainage back to the previous stage and 50% of the drainage to the next stage. It is assumed that most or all of the fluids will run to the previous stage. As a part starts taking on water from the next stage, it uses the remaining 50% drain to ensure that fluids don't drain into the prior stage. Drainboards are located between washer stages and channel the fluid to or from the stage. Equipment manufacturers or consultants can assist in determining proper drain lengths for an application.

Washer Options

Many varieties and configurations of washers are on the market. As one would expect, every equipment company seems to believe it has the best pretreatment system available. It truly pays for any manufacturing or production facility to do the homework of investigating available options. Each option has its place in pretreatment, but may be unacceptable for a particular operation.

Training on the process of pretreatment is an absolute must before attempting to purchase a wash system. An individual who has some training and who knows the washer processes is better suited to ask the pertinent questions. Questions include:

- Is the need for steel, stainless, or polyethylene (poly) substrates?
- What equipment and processes are affordable?
- How much room does the equipment require?
- Acid or alkaline?
- Testing?
- How many steps are involved to make the best quality product for the least cost?

Generally, industry prefers multi-stage systems allowing the functions of cleaning, rinsing, conversion coating, and possibly

sealing, the part. The type of system presents flexibility within the specific process.

Powder coating requires a clean substrate surface. This usually requires a three-to-five-stage washer. Three-stage washers can be used if soils are minimal. The three-stage system requires tight process controls.

Some of the washer types are:

- steel,
- stainless steel, and
- plastic.

Steel

Steel washers are easy to fabricate and economical to purchase. They are good washers for companies with smaller budgets who cannot cover higher-priced equipment.

Steel washers are cheaper than stainless steel washers, but have a limited operating life of approximately 10 years. Not many iron washers are in good condition after a decade of use. Major maintenance is often needed (this is not always the case . . . but usually). Steel washers tend to have higher levels of TDS compared to other styles of washers, because they are in constant oxidation. Rust comes off of the washer walls and ceiling, falling into the water continually. It is harder to descale these types of washers to eliminate the rust inside. Some companies try to clean and repair their steel washers by sandblasting the inside and coating them with a compound. This can be effective. However, it is a weekend job because it is dirty work and leaves billowing clouds of material racing out the ends of the vestibules. The sandblasting may open holes in the washer housing that will leak water if coatings are not applied to the washers.

Steel washers do not have much chemical resistance.

Stainless Steel

Stainless steel washers usually last a long time. Their major drawback is their price. Stainless steel is more expensive than steel. It has improved chemical resistance and does not drop oxides into

the bath. Usually the only buildup on the washer walls is from the mist and spray from the risers. This buildup is easily descaled. Stainless steel washers can provide 15–40 years of service. In building these washers, consider stainless-wetted pumps. Most stainless-steel tanks are constructed with 3/16-in. (0.48-cm) type-304 stainless steel plate. The washer-housing walls and roofs are usually 14-gage stainless steel.

Plastic

More equipment manufacturers are developing poly washers. Poly has some advantages. It lets light into the washer housing so maintenance is better accomplished; it is easier for the equipment supplier to build than other types of washers; and it does not rust. A problem with poly washers is leaks at the joints. Some of these leaks can occur where holes are drilled (to mount various items), or in plastic separation where water worked its way into the drilled holes.

Some suppliers offer a 10-year guarantee on their poly washers (in contrast to a one-year guarantee on stainless steel washers). Anyone interested in purchasing poly washers need to do their homework and review more than one washer.

DEIONIZER (DI) DESIGNS

Deionizer designs fall into two general types: multi-bed and mixed-bed. Some systems combine these two types.

Multi-bed Design

A *multi-bed design* is chosen when more than one bed of deionizer resin is required to make up a system. It may consist of one bed (in one tank) of cation resin, followed in a series by one bed (in one tank) of anion resin. Such an arrangement is a two-bed system. Another arrangement is a three-bed system, consisting of a tank of cation, with a tank of weak-base anion, followed by a tank of strong-base anion resin. A still more elaborate system consists

of a tank of cation, a tank of weak-base anion, a tank of cation again, and a tank of strong-base resin.

In some arrangements, a unit called a *degasifier* is placed in line after the cation tank. The purpose of the degasifier, or vacuum deaerator, is to remove carbon dioxide and/or oxygen from the water. This makes the water much less corrosive when used in steel equipment such as high-pressure boilers. Removal of the carbon dioxide also reduces the exchange load to a strong-base resin in the system.

Mixed-bed Design

A *mixed-bed design* allows two resins—cation and strong-base anion (only)—to be carefully and thoroughly mixed in a certain ratio and then added into a single tank. A typical ratio is 60/40, where the strong-base anion makes up 60% of the total-resin mix and the cation makes up 40%. Mixed-bed deionizers are capable of producing water higher in chemical purity than is possible in multi-bed designs. A multi-bed system with strong-base-anion resin can produce 100,000–500,000-ohm water. A single tank of mixed-bed resin can produce water with 1,000,000 ohms of resistance or higher. Arranging two or more tanks of mixed-bed resin in a series can result in water purity reaching 18,000,000 ohms.

Some systems combine multi-bed and mixed-bed units. The former removes the bulk of the ions; the latter takes out the remaining ions, thus giving larger volumes of high-purity water than if mixed-bed alone were used. Mixed-bed units used in this manner are called *polishers*.

Systems that combine both multi-bed and mixed-bed units take up less floor space, may cost less, and produce higher-quality water. They also use less rinse water during regeneration. Regeneration is more complicated, however, since the two resins must be separated physically within the same tank, and regenerated individually with different regenerants. In deionizer-exchange tanks, mixed resins are removed from those tanks and separated into individual regenerating tanks.

The amount and type of anion resin determines the capacity. Ratings are in grains of removed ions per cubic foot of resin and

depend on the type of anion resin, whether it has a weak or strong base, and the amount and kind of regenerants. Since a weak-base resin exchanges only chloride, nitrate, and sulfate ions, there is a higher-capacity rating. When DI systems using weak-base resins are involved, water analysis requires only the determination of these strong anions.

REVERSE OSMOSIS (RO)

Osmosis is a natural phenomenon in which a liquid—water in this case—passes through a semipermeable membrane from a relatively dilute solution toward a more concentrated solution. This flow produces a measurable pressure, called *osmotic pressure*. If pressure is applied to the more concentrated solution, and if that pressure exceeds the osmotic pressure, water flows through the membrane from the more concentrated solution toward the dilute solution. This process is called *reverse osmosis*. It removes up to 98% of dissolved minerals, and virtually 100% of colloidal and suspected matter. RO produces high-quality water at a low cost when compared to other purification processes.

The membrane must be physically strong to stand up to high-osmotic pressure. Most membranes are made of cellulose acetate or polyamide composites cast into a thin film, either as a sheet or fine hollow fibers. The membrane is constructed into a cartridge called a RO module, as shown in Figure 7-1.

After filtration to remove suspected particles, incoming water is pressurized with a pump to 200–400 psi (1,379–2,758 kPa), depending on the RO-system model used. This exceeds the water's osmotic pressure. A portion of the water (permeate) diffuses through the membrane leaving dissolved salts and other contaminants behind with the remaining water where the salts and contaminants are sent to drain as waste (concentrate).

Pretreatment is important because it influences permeate quality and quantity. It also affects the module's life because many waterborne contaminants can deposit on the membrane and foul it. Generally, the need for pretreatment increases as systems become larger and operate at higher pressures, and as the permeate quality requirements become more demanding.

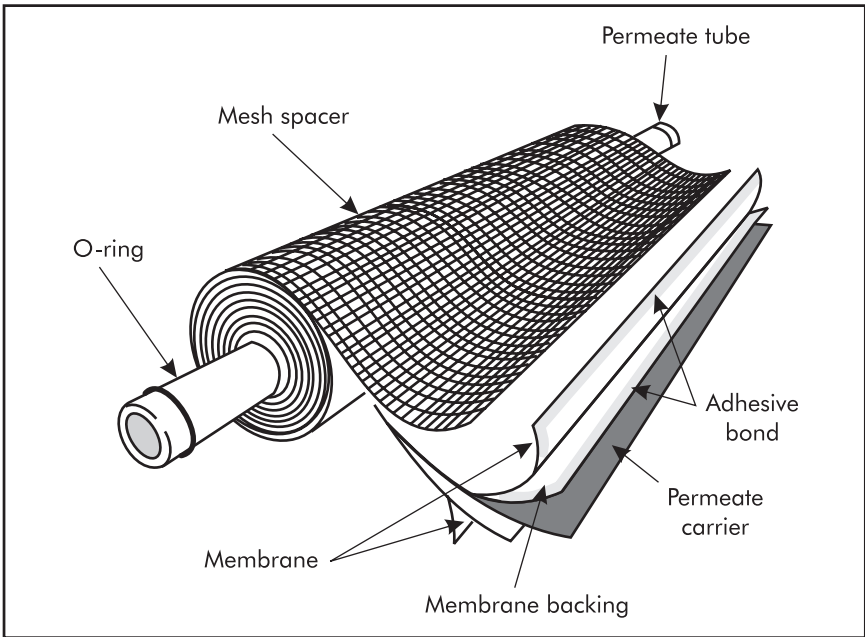


Figure 7-1. Spiral-wound separator (membrane element).

Permeate production increases with increasing pressure and temperature. RO systems are rated at the standard temperature of 70° F (21° C). When the feed-water temperature is lower than this standard, the system size must be increased to compensate for lower production. Membrane fouling also may reduce production by as much as 8% at 200 psi (1,379 kPa) and as much as 20% at 400 psi (2,758 kPa) in three years.

There are several theories about how water and salt pass through semipermeable membranes. One suggests that the membrane is porous, containing many capillaries through which pure water flows. Another suggests a solution/diffusion mechanism in which water continually dissolves into the membrane on the pressurized side and diffuses out the other. In either case, dissolved inorganic and organic matter cannot pass through the membrane to any great extent. In systems using cellulose acetate membrane, somewhere between 35–50% of the feed water can be drawn off (recovered) as permeate. In larger systems using polyamide membranes, recovery can reach 80%.

PRETREATMENT STAGES

Conveyorized pretreatment washer systems take advantage of a consistent and efficient way of processing parts for cleaning. Parts are hung on parts racks prior to entering the washer system. This entry is an *entrance vestibule*. This vestibule prevents water from exiting the washer. As one might expect, the *exit vestibule* is located at the end of the washer. Fans are installed in these vestibules to draw out the steam and moisture and bring it to the roofline. These fans remove any vapors from the building.

Within the vestibule, parts enter into stages. Each area of the system that the part passes into performs a mechanical function called a *stage*. Stages may be divided into *zones*. Most stages are designed similarly, but may have longer zones, different nozzle configurations, and different chemical or rinse functions.

Each pretreatment stage is composed of a tank to hold the fluid, the washer walls and roof, pumps, piping, risers, and nozzles. Tanks should be of sufficient capacity to turn the fluid over approximately every 2.5–4 minutes. This turnover ensures that the chemicals or rinse waters will not become stagnant. The length of the washer stage is directly related to the line speed and the time the part should be in the stage for proper processing.

Tank floors should be sloped to aid draining. Many equipment companies use 3° pitch (approximate) for the slope, although a greater slope is needed to completely evacuate and drain the tank's fluid. (And waiting for these tanks to drain can try anyone's patience. The task is not "labor-effective." Plant floors usually are not level, adding to the difficulty of proper draining. The heater-tube placement within the tank partially controls the tank floor's pitch. Roof panels should be pitched toward the machine's wall so moisture does not drip onto the substrate.)

Some stages of the washer system are heated stages. These heated stages make the chemicals within the tank far more effective. Some types of heating methods are:

- immersion tube,
- plate coils,
- plate and frame heat exchangers, and
- electric coils.

Immersion Tube Heating

The immersion tube is the most widely used heating method in washer tanks. In an immersion tube heating system, a hollow serpentine tube runs through the lower portion of the tank, as shown in Figure 7-2. A burner located outside the washer tank forces heat through this tube. The burner is exhausted to the outside atmosphere at the opposite end of the tube. As the tube reaches higher temperatures, the fluid temperature around the tube also rises. As the tube is serpentine, use of the heat source is maximized. There are different efficiency ratings for the burners firing the tubes and the tubes themselves.

Plate Coil Heating

Plate coils are tube-type heat exchangers and are heated using steam heat from an outside source within the plant. They provide

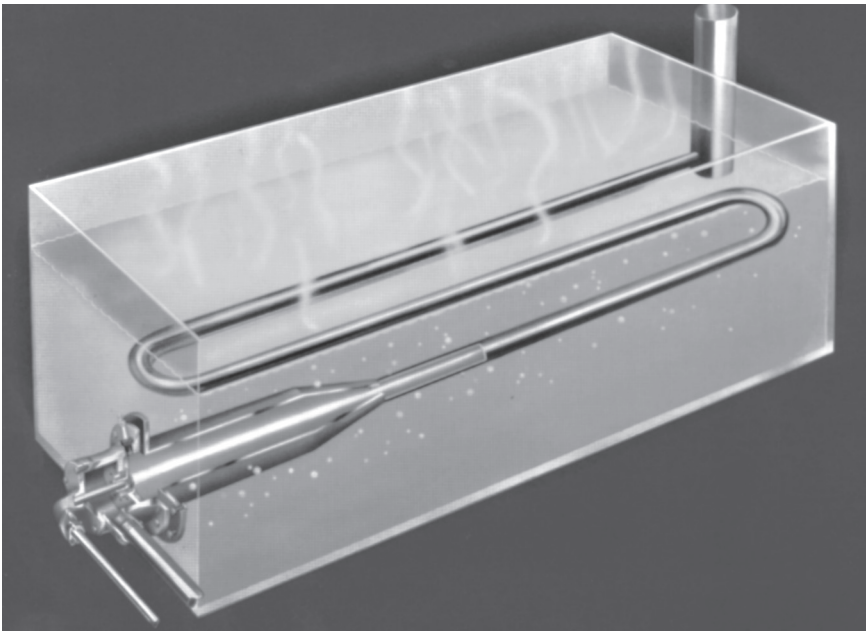


Figure 7-2. Immersion tube heating system.

heat by transferring heat energy from the steam within the coil to the solution passing over the coil's surface.

Plate and Frame Heat Exchangers

In heating processes using plate and frame heat exchangers, the heat sources are located outside the solution tank and are connected to a steam or hot water source. Solution is pumped into the exchanger through a separate path and run back into the tank.

Electric Coil Heating

Electric coils are a type of in-tank heater typically used in smaller systems. Electric heaters are not as efficient as gas burners. They take longer to reach operating temperatures and tend to lose temperature on starting the washer.

TANKS

All tanks should have screens between the main tank and the pump. The screens stop the entry of soils or debris into the pump, which reduces the pump's production life. These screens need to be cleaned regularly (usually each shift). Screen assemblies should be sized at 1.0 ft² (0.093 m²) of open area per 100 gal/min (379 L/min) flow. Screens are generally fabricated from 18-gage material.

Tanks need access lids for cleaning and solution testing. Lids should extend beyond the housing on the pump side and allow easy access to the screens. Lids should be hinged and have lid keepers and extended handles for safety. (The handles are to prevent the operator from leaning over hot chemical to open or close the lid.)

Tanks need quick fills and drains. (A *quick fill* is the incoming freshwater pipe used to fill the pretreatment tanks. The water can be either city freshwater, deionized water, or water from reverse osmosis.)

Most washer equipment companies provide a 1.5-in. (3.8-cm) fill assembly and a 2-in. (5.1-cm) drain. Adding a 2-in. (5.1-cm) quick fill and a 3-in. (7.6-cm) drain helps considerably with washer cleaning. With enough pressure to use a 2-in. (5.1-cm) fill, the cleaning process is quicker before refilling the tanks. Likewise, a large drain allows water to escape these tanks more quickly, saving labor.

Heated stages in a washer need automatic level controls to maintain the tank's correct fluid level. There should be a high/low temperature sensor and an alarm to alert users to temperature problems. Most insurance companies demand a low-liquid-level control to prevent the pump from running dry if the fluid level drops.

The cleaner stage(s) needs oil skimmers to capture oils or effluent floating to the surface.

The housing walls, roof, and tank of heated stages need insulation and flashing to conserve energy.

Access doors should be installed on the washer's pump side to facilitate maintenance. Handrails on the stair or platforms are good ideas, because moisture can make the steps slippery. At each door, access lights (such as dock lights) should be provided. To provide exceptional lighting as an aid in maintaining a washer, consider the following steps:

- cut a hole into the roof panel in each operating stage;
- install glass with a rubber boot;
- install high-output fluorescent lighting above the roof.

These steps allow a user to monitor the process. In addition, each door should have a 120 V duplex receptacle with hinge flap for maintenance.

Other parts within tanks include:

- Drainboards located between washer stages channel fluid to or from stages. In between the stages where cleaning, phosphatizing, rinsing, and sealing occurs, the parts are dripping liquid from the stage they came from. Drainboards direct the liquid back to the area it came from, prohibiting it from contaminating the next stage.
- Made from the same material as the washer, silhouettes are divider sheets separating each stage. Silhouettes are installed

in each stage near the entrance and exit. A silhouette keeps fluid from spraying outside the stage when fluids impinge against the substrate and reflect away. Silhouettes usually are sized for a part clearance of 6 in. (15.2 cm).

- Pumps should be designed to allow the motor to be removed from the barrel assembly if necessary without disturbing the base plate. They should have an extended tail pipe at least one size larger than the pump inlet and they should terminate one pipe diameter from the tank bottom. The entrance to the pump should be close to the tank's bottom—this makes it difficult to run the pump dry if the tank's liquid level should fall.
- Risers are the piping that comes from the header. The header comes from and is fed with high-pressure water from the pumps. Risers are generally spaced at 12 in. (30.5 cm) increments but can vary, depending on the parts to be sent through the washer. Spacing can be 9–22 in. (22.9–55.9 cm). (The line speed determines the exact distance between these risers.) The faster the line speed, the wider the spacing needed. A widely used riser diameter is 1.25 in. (3.2 cm).

CONVEYORS

Conveyors can run inside or outside of the washer. Running the conveyor outside the washer protects it from rust and prevents outside contamination's entry into the washer.

To calculate the time a part remains in the washer, measure the distance between the first and the last riser within the stage and divide that number by the conveyor speed. As a case in point, presume:

- 16 risers in the spray zone,
- at 12 in. (30.5 cm) incremental spacing,
- and a needed conveyor speed of 10 ft/min (3.05 m/min).

In this case, there is actually 15 ft (4.6 m) between the risers. Therefore:

$$\frac{15}{10} = 1.5 \text{ min (or 90 sec)} \quad (7-1)$$

NOZZLES

Nozzles are placed differently on each specific washer. However, usually, nozzles are placed on each side of the washer, facing downward from the washer's roof and upward from the tank's floor. Thus, the part receives good impingement from the nozzles.

Nozzle placement per riser is usually spaced at 12 in. (30.5 cm) increments. There are a variety of sizes and shapes of nozzles for specific applications. Most typical power washer applications use a "V" jet to clean with impingement. These "V" jets can be ordered by tip size, angle of fluid deflection, and volume of fluid exiting the tip. Most washers have poly nozzles for easy cleaning and repair.

Hollow cone swirl-jet nozzles are available for the phosphate stages. High-pressure impingement is unnecessary for this operation as the phosphate nozzles apply only the chemical. The acids in the chemical attack the part to provide an etch on aluminum or a phosphate coating on steel.

Misting nozzles are sometimes installed between stages to keep the parts misted with fresh water so they do not dry and flash rust.

In building nozzles, some chemical companies started out using black iron piping and threaded stainless steel nozzles and moved to 80 CPVC piping as it is easier to work with. Some chemical pretreatment companies still specify black pipe for the cleaner stages, as these stages include harsh, caustic chemicals. The new nozzles are easily snapped into place or removed for cleaning and replacement. The newer plastic nozzles also cost less than the threaded stainless steel type.

Generally, nozzle performance is related to the pressure of impingement and the area covered by the impingement. Bigger parts present the challenge of more area coverage. Any impingement area should have overlapping spray patterns to provide proper cleaning and/or rinsing. Pretreatment suppliers and equipment suppliers can assist with this design.

Risers can be designed with either single or staggered patterns. Single riser spray patterns match each other at the middle (if there were no parts). Staggered patterns do not match each other. The part itself usually dictates the usage. Table 7-1 shows stage specification and Table 7-2 shows typical process specifications.

Table 7-1. Typical five-stage specifications

Physical Specifications		
• Housing width—6 ft (1.8 m) • Housing length—72 ft (21.9 m) • Housing height—8 ft (2.4 m) elevated on 4-ft (1.2-m) high tanks • Overall height—12 ft (3.7 m)		
Design Specifications		
Area	Length	Time
Entrance vestibule	6 ft (1.8 m)	
Stage 1—Clean	16 ft (4.9 m)	90 sec
Drain	6 ft (1.8 m)	
Stage 2—Rinse	4 ft (1.2 m)	30 sec
Drain	6 ft (1.8 m)	
Stage 3—Iron phosphate	8 ft (2.4 m)	60 sec
Drain	6 ft (1.8 m)	
Stage 4—Rinse	4 ft (1.2 m)	30 sec
Drain	6 ft (1.8 m)	
Stage 5—Seal	4 ft (1.2 m)	30 sec
Exit vestibule	6 ft (1.8 m)	
Total	72 ft (21.9 m)	

THREE-STAGE SYSTEMS

Stage I

Figure 7-3 shows a three-stage washer system. Stage 1 combines cleaning and phosphates. Acidic cleaners must remove soils prior to depositing the phosphate etch. To accomplish this task requires 90 seconds (minimum). Temperatures need to be approximately 110–160° F (43–71° C). Typical chemical concentration levels are around 2–3% by volume. The nozzle pressure of this tank ranges between 10–25 psi (69–172 kPa). This cleaner/etch stage requires that additional surfactants and pH correcting agents be added during the titration process to keep the stage within specification.

Table 7-2. Typical process specifications sheet

Stage	Solution	Time sec	Temp °F (°C)	Number of Risers	Number of Nozzles	Nozzle		Pump		Total Dissolved Solids	pH	Tank Capacity gal (L)	Input pH	BTU/hr (J)
						Type	Pressure lb/in. ² (kPa)	Nozzle gal/min (L/min)	Cap gal/min (L/min)					
1	Cleaner	90	140 (60)	9	90	BF5060	20 (138)	4.2 (15.9)	380 (1,439)	70	10	1,570 (5,943)	426 (449,454)	
2	Rinse	30	—	5	50	BF5060	20 (138)	4.2 (15.9)	210 (795)	70	7.5	850 (3,218)	Not heated	
3	Iron phosphate	60	140 (60)	9	90	BPH 28	15 (103)	3.4 (12.9)	305 (1,155)	60	10	1,260 (4,770)	342 (360,829)	
4	Rinse	30	—	5	50	BF5060	15 (103)	3.7 (14.0)	185 (700)	60	7.5	770 (2,915)	Not heated	
5	Seal	30	120 (49)	5	50	BF5060	15 (103)	3.7 (14.0)	185 (700)	60	7.5	1,020 (3,861)	207 (218,397)	

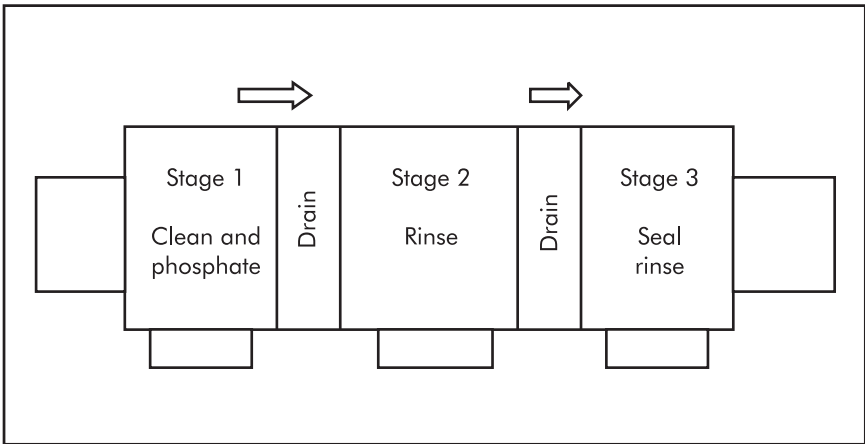


Figure 7-3. Three-stage washer system.

Stage 2

In Stage 2, clean water rinses chemical residue and drag out brought from Stage 1 off of the part. The ware should be rinsed for at least 45 seconds. This stage also stops the phosphate reaction on the substrate's surface. The total dissolved solids (TDS) should never reach more than 1,000. A much lower TDS reading of approximately 250–500 is preferred.

Stage 3

In Stage 3, the final seal removes any residual chemical remaining on the ware, preventing flash rusting and improving overall performance. The ware should be in the stage for 30 seconds. The temperature should be 90–140° F (32–60° C). The pH of this stage is slightly acidic and is approximately 5.0–6.0.

Helpful Hints

In using a three-stage system, pay particular attention to the following:

- Be certain that the pH level is monitored regularly. If pH levels rise too high (pH over 5.0), spotty areas on the iron substrate appear. Some areas appear shiny and some bluish or green colored. The reason: insufficient pH strength to evenly cover the entire surface. In turn, the part will not have uniform adhesion and ultimately has poor, spotty adhesion in some areas. If pH needs to be increased, add some pH corrector to lower it to specification.
- Make certain the temperature is within tolerance so the heat can assist in breaking-down the soils. Usually heat is needed to clean soils. Remember: surfactants generally require heat to do their job aggressively. In Stage 1, without heat of over approximately 110° F (43° C), the tank foams violently and overflows any opening.

FIVE-STAGE SYSTEMS

Figure 7-4 shows the process flow for a five-stage system. This discussion will cover four items for each stage. They are:

- chemical composition,
- time in the stage,
- temperature, and
- impingement pressure.

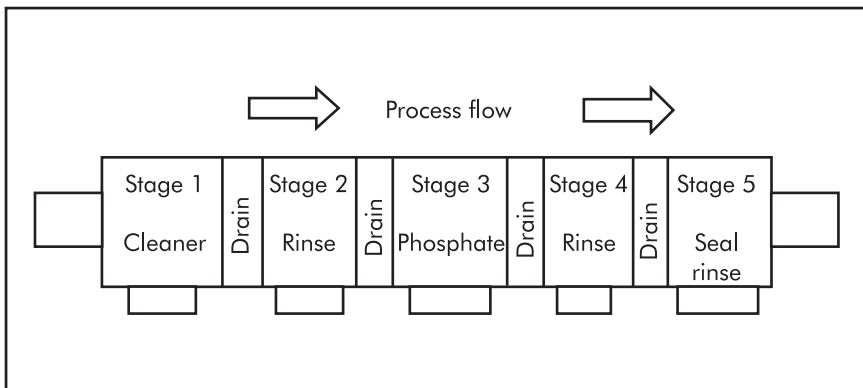


Figure 7-4. Five-stage washer system.



Stage 1

Stage 1's sole purpose is to clean the part. Alkaline chemistries are applied in this stage and are far superior to the combination chemistry where the part is first cleaned then receives a phosphate coating. The ware must be in this stage for a minimum of 90 seconds. Temperatures should be approximately 110–160° F (43–71° C). Typical chemical concentration levels need to be close to 2–4% by volume.

Stage 2

Stage 2 uses clean water to rinse off chemical residue and drag-out brought from Stage 1. The ware should be rinsed for at least 45 seconds. The TDS should never exceed 1,000.

Stage 3

Stage 3 applies the phosphate coating to the ware. The ware should be in the stage for 60 seconds. The temperature should be 90–140° F (32–60° C). The pH of this stage is slightly acidic and is approximately 4.0–5.0.

Stage 4

Stage 4 uses clean water to rinse off chemical residue and drag-out brought from Stage 3. The ware should be rinsed for at least 30 seconds. This stage should have a much lower TDS reading of approximately 250–500.

Stage 5

This final seal stage—Stage 5—removes residual chemical left on the ware, preventing flash rusting from occurring and improving overall performance. The ware should be in the stage for 30 seconds. The temperature should be 90–140° F (32–60° C). The pH of this stage is mildly acidic and is approximately 5.0–6.0.

DETERMINING THE INITIAL CHARGE

To determine the initial charge needed in a particular tank, try the following:

- Multiply the tank width by the tank length by the fluid level height and multiply by 7.5 (because there are approximately 7.5 gallons of fluid in a square foot [40.75 liters of fluid in a square meter]). This results in the total square feet (square meters) of fluid in the tank (see Figure 7-5).
- Multiply the volume of fluid in the tank by the percentage of chemicals in the tank according to the tank size. For example, if a 2% concentration is needed in a 100 gal (379 L) tank, 2 gal (8 L) of raw chemical should make up the bath.

Put another way,

$$\text{initial charge} = W \times L \times H \times 7.5 \times P \quad (7-2)$$

where:

W = tank width, ft (m)

L = tank length, ft (m)

H = fluid level height, ft (m)

P = percentage specified for the tank

For example, if:

$W = 20$ ft

$L = 10$ ft

$H = 3$ ft

P = percentage specified for the tank (in this example: 3%)

then:

$20 \times 10 \times 3 \times 7.5 \times 0.03 = 135$ gallons of chemical to charge initially at 3% by volume

BASE AND ACID DEFINITION

All liquids are base, acid, or something in between. The potential of hydrogen is pH. Water's pH level is 7.5 (approximately) and changes slightly depending on the geographic region of the

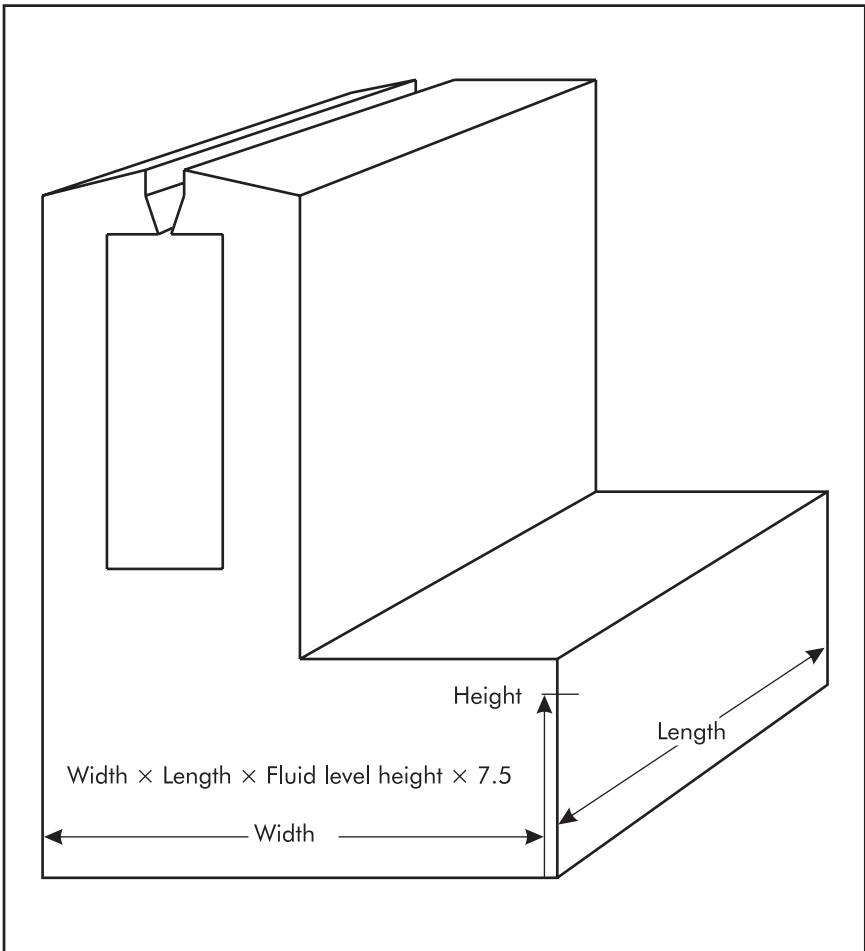


Figure 7-5. Determining initial tank charge.

world. Acid is the opposite of alkaline or base. On a scale of 0.0–14.0 pH, acid would be at the 0.0 pH end and alkaline/base at the 14.0 pH end. Presume that H_2O is at 7.5 pH.

Anything less than 7.0 pH is considered acidic with lower numbers representing stronger acid. Anything over 7.0 pH is considered alkaline with the stronger alkaline being the higher number. Thus, a pH of 1.0 is a strong acid and a pH of 13.0 is a strong alkaline, as shown in Figure 7-6.

Keep acids and base material away from each other.

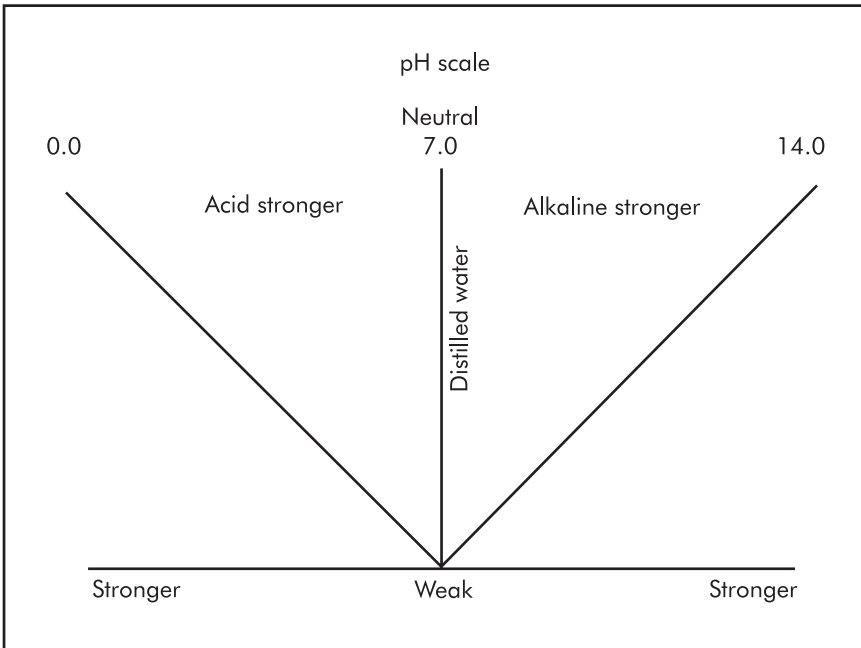


Figure 7-6. pH scale.

MEASURING WASHER ZONE TIME

To determine the time a part would spend in any zone, measure the feet (meters) between the first and last riser. Then divide that by the line speed.

Stage I

In this example, presume the following: 20 ft between risers and 20 ft/min is the line speed. Using Equation 7-1,

then:

$$\frac{20}{20} = 1 \text{ minute}$$

One minute is not enough time in the cleaner stage. Remember that the end risers are usually angled toward the washer's center so impingement spray does not spray into other zones or outside the

washer vestibules (ends). Measurements must be taken from the inner spray areas in this case, not at the riser itself.

Stage 2

Stage 2 uses clean water to rinse off the chemical residue and dragout brought from Stage 1. The ware should be rinsed for at least 45 seconds. This stage helps neutralize alkalinity coming from Stage 1. Stage 2 is not a heated stage. Carryover from Stage 1, along with heat coming from the part, eventually raises the tank temperatures dramatically.

Temperatures can be only a few degrees difference from Stage 1 to Stage 2. This added heat sometimes assists with the removal of organics remaining after the cleaner stage(s). The impingement is 10–25 psi (69–172 kPa). This amount is slightly higher to assist with cleaning.

Stage 3

Stage 3's sole function is to apply a uniform conversion coating, thus creating improved bonding power. The ware must be processed for 60 seconds in this stage. Typical pH levels are approximately 4.0–5.0. Temperatures are 120–150° F (49–66° C). Impingement pressure is approximately 10–15 psi (69–103 kPa). It is important to note that high pressures are unnecessary because the acid is only being applied and is allowed to work itself. The impingement action is not required.

Stage 4

Stage 4 is a rinse stage designed to flush any residual phosphate from the ware and to clean the part prior to sealing it in Stage 5. The ware should be processed for 30 seconds in this stage. Temperature is ambient (air temperature). Impingement is 10–15 psi (69–103 kPa).

Stage 5

The purpose of this final sealing stage—Stage 5—is to remove unreacted phosphate, to cover bare spots on the coating that was not previously etched, to prevent flash rusting from occurring, and to give the product extended salt-spray performance. The ware should be processed for 30 seconds in this stage. Temperatures should be 90–140° F (32–60° C). The pH is approximately 5.0–6.0. Impingement is 10–15 psi (69–103 kPa).

RINSING

Rinsing is an integral part of pretreatment for powder-coat operations. It must function as a system with the other baths. Various rules can apply to all rinses. Some of these rules include the following:

- It is much easier to rinse an acidic surface than an alkaline surface. This is probably because the hydrogen ions on an acidic surface bond more readily with a water rinse than do the hydroxyl ions on an alkaline surface.
- Rinses should not exceed 300 ppm TDS in the last stages of any washer. Higher readings indicate a rinse is likely to be redepositing salts onto a part instead of removing them.
- Heated rinses are generally unnecessary. However, because cleaner stages are usually heated, parts exiting the hot cleaner warm the next rinse. This extra warmth is beneficial because it improves alkaline rinsing efficiency. Heated final rinses are sometimes used on paint lines without dryoff ovens to speed drying before painting. Heated sealer rinses may cause unfavorable chemical reactions in the bath.
- Precautions need to be taken to prevent bacteria and fungi growth in rinses, especially in a nonchrome sealer rinse. Chrome seals automatically keep bacteria and fungi growth in check. One plant actually has mushrooms growing in its sealer rinse. It is wise to periodically purge tanks and piping with bactericides and fungicides. Water storage tanks are great spawning beds for fungi growth, especially in reverse

osmosis and deionized systems. Biannually, the tanks should be cleaned using household bleach or peroxide to kill bacteria contaminants. Green fungi occasionally grow in the water treatment systems' flow meters of the control panel. A combination of three causes contributes to the growth of the fungi: stagnant water; a working height in the storage tank that does not let water stay fresh; and overhead lighting giving nourishment to bacteria that feeds the fungi.

- Fill storage tanks to a level that the system uses in a reasonable amount of time. If wash stages are to be drained as part of the cleaning process, fill the storage tank completely. Keep the water moving; stagnant water builds bacteria quickly. Last, cover the tanks to block light. Some tanks can be bought with colors embedded in them to cut down on light rays. TDS meters will reveal problems with bacteria or fungi.
- Gentle overflow is recommended for all rinses.
- Precaution must be used when counterflowing rinses. Sometimes the rinse after conversion coating is counterflowed to the rinse before the conversion coating. The rinse after the conversion coating tends to be acidic. This can help neutralize the rinse after cleaning (this rinse tends to be alkaline). The rinse being counterflowed must be kept clean to prevent the possibility of precoating parts—a step that would interfere with efficient conversion coating.
- Spray-rinse volume is much more important than spray impingement. Large amounts of water improve rinsing efficiency. Impingement pressure is important in the cleaner stage.

Counterflowing

Counterflowing keeps water usage to a minimum. Generally, many pretreatment systems overflow rinse stages to the drain. This keeps the TDS level in specification. The problem with this method is that the water drained is wasted. Counterflowing this water to prior stages, rather than overflowing to drain, makes use of the resource and saves money.

Seal Rinses

Seal rinses, whether they are used in a three-stage or five-stage system, remove unreacted phosphate, cover bare spots in the coating, prevent the surface from flash rusting, and extend salt-spray performance. There are three types of seal rinses: deionized water, acidic, and reactive. Reactive rinses came on the market in 2000. They may not always be on the acidic side and, because of their chemistries, some are actually slightly alkaline.

Spray Wands

Spray wands are used in lower-production systems. With spray wands, parts are manually cleaned and phosphatized. Making sure of the high pressure and proper chemical addition within the machine helps ensure satisfactory performance.

Blow-off

Blow-off systems use compressed or forced air to blow water off the exterior of parts as they come from the power washer. These systems are designed to be a rinse aid prior to the dry-off stage. The system can be automatic or manual and may be ionized. It can use high-pressure air or a high volume of air.

Compressed air is forced through nozzles or air knives and directed at the cleaned part. High-pressure knives work well when dealing with heavier parts; however, the system would also blow clear any smaller parts. Manual blow-off systems consist of handheld compressed-air blow-off devices. The blow-off device is aimed at the part and it is moved across the surface, blowing off the water.

Monitoring and Maintaining Pretreatment Systems

Pretreatment chemical and system suppliers will recommend maintenance, monitoring, recording, and chemical schedules. They may even provide the service as well. These recommendations are critical because wash systems need continual monitoring since they constantly change. The changes affecting wash systems include:

- the product being cleaned;
- the concentration, total dissolved solids (TDS), and pH levels;
- the age of the bath; and
- to clean the surface of the substrate, each substrate requires more or less impingement than the previous substrate.

A powder-coating user needs sufficient pressure to properly clean the soil from the part. Cleaning a large heavyweight object requires the part to be run more slowly through the wash system to enable the temperature and impingement action to work. A user must be able to decrease or throttle the pressure applied to smaller lightweight parts, or parts will be lost into the tank. Too much pressure and the lighter-weight parts may be forced from the holding rack and damaged as they are thrown into the tank.

A user needs to be concerned as the TDS climb. TDS levels need to be controlled at appropriate intervals. In addition, the concentration level changes due to the part's geometric configuration and the washer itself as:

- The part's geometric configuration may tend to carry out chemicals from the prior stage(s) and dilute the remaining stages (this is referred to as *cupping action*).
- The amount of dirt or soils on the part reacts with the batches/chemicals to change their original pH.
- The amount of product in the bath can make the concentration change.
- The heated stages can lose the water portion due to the high dehumidification of the path occurring from high temperatures. The chemicals are unaffected by this humidity loss and thus tend to become stronger as the water loss becomes evident.

If the part does not drain or if chemicals are dragged from stage to stage, the initial cleaner stage will have fewer chemicals in the bath to properly clean the substrate. Also, since cleaner baths require a temperature between 120–160° F (49–71° C), some water will be lost to evaporation. Even though water evaporates, there is no loss of chemicals. So if the evaporated water is not replaced, the chemical concentration levels increase. This is never good.

Bath life is always a concern. Issues to consider include:

- The type of system: is it a three- or five-stage system?
- What kind of soils are on the substrate?
- How often is the washer operated, one or three shifts?
- Are oil skimmers and/or a filter used to aid in the removal of contaminants? (Ultimately, there is a time when bath life is exhausted and dumping is required.)

Some companies do not dump their complete tank. Instead, they let the tank settle overnight and skim the clear fluid left on top. This fluid is usually transferred temporarily to a rinse tank until the tank being cleaned has had the sludge cleaned out. This method is referred to as *decanting*.

TOTAL DISSOLVED SOLIDS AND pH

Total dissolved solids (TDS) and pH levels are indicators of water cleanliness.

TDS and pH levels should be checked and recorded daily. Visual observation alone causes ineffective rinsing and water waste. The

pH of water shifts up or down when it is used effectively. This shift depends on many factors. The factors with the most impact are:

- alkalinity or acidity strength of the preceding chemical stage;
- part shape, size, length, and configuration;
- rinse-stage design; and
- overflow volume.

Ideally, TDS and pH levels in rinse tanks should be the same as those in incoming water. However, this is not typical in actual production. In general, rinse-tank pH should be within ± 1.5 –2 points of the incoming water pH, and TDS should be no more than twice the initial reading for rinse stages between active chemical tanks. Tests comparing TDS and pH values measuring adhesion, chemical use, and humidity are the only true way of knowing the answer.

A user should presume that 1,000 μmho or more is a sufficient amount of TDS to show up on the painted surface as a defect. Most water is measured for cleanliness with a TDS meter. Conductivity and TDS are related. A conductivity meter measures the water's ability to allow an electrical current to flow through it.

Liquids, like high-purity water, have few ions and, thus, are poor conductors. A conductivity measurement can estimate TDS levels in water. However, measuring the electrical conductivity provides only an estimate of the TDS levels in water because conductivity is not precisely proportionate to the weight of an ion, and nonconductive substances cannot be measured by electrical loss.

TDS have been dissolved in solution and exist in ionic and non-ionic form (an example of this is isopropyl alcohol). Even though it has a high purity level, an attempt to measure the conductivity results in a zero reading.

Deionized (DI) water rinsing leaves rinsed substrates in a slightly acidic state. In the DI exchange process, the resins remove everything, including carbon dioxide, carbonic acid/ CO_2 , and alkalinity, leaving very pure water. Once this water is released to the atmosphere from the exchange process, it starts absorbing carbon dioxide or CO_2 . It continues absorbing CO_2 and, without the alkalinity to buffer it, the pH level drops until a maximum saturation level is reached, resulting in a pH level always remaining at

5.0–7.0. The water is slightly acidic as the pure water does not reabsorb the alkalinity it processed out.

The reverse osmosis (RO) water process does not remove the carbon dioxide in its exchange process, but does remove alkalinity at a rate of 98%.

Using RO water as a rinse agent or tank fill can be cost efficient. It is important to keep the water's usage to a minimum yet sufficient to properly rinse the substrate. Effective rinsing is controlled by water cleanliness. Water cleanliness means that the bath will "live longer" between dumps.

Test water after equilibrium. If the application uses a mixed-bed or clean DI water, a resistivity meter should be used. A pH meter requires the electrode to measure water that has conductivity in it. DI water—if cleaned properly—has little conductivity. Some manufacturers add a known salt "standard" to the water when testing it. Many companies try and test without these salts and get erroneous readings from their meters. They think their meter is not working, when in fact, the meter cannot function with this level of water cleanliness.

Calibration Procedure

Figure 8-1 shows a meter that measures total dissolved solids. The following procedure must be undertaken:

1. Using the TDS/conductivity standard solution, pour enough into the TDS testing cup to rinse previous residual solution clean. This should be repeated again, letting the last solution remain in the cup.
2. Set the dial indicator on (1,000) and depress the toggle button. The meter reading should be exactly the same as the TDS/conductivity standard solution sample. Be sure to depress the toggle at least three times to get an accurate read-out as it takes a few moments to standardize.
3. If the reading is "OUT" of calibration, open the bottom of the TDS meter. An adjustment dial allows the user to set the dial to the known standard solution. It is critical to have the



Figure 8-1. Total dissolved solids meter.

known standard solution in the TDS cup to set the standard and ensure it is current.

PHOSPHATE COATINGS

Phosphate coatings are generally used for the following reasons:

- to provide a base for bonding organic finishes such as paints, lacquers, plastics, rubber, adhesives, and powder coatings;
- to provide a base for oils, waxes, and rust preventives to reduce corrosion;
- to provide a base for lubricants on bearing surfaces to reduce friction; and
- to aid in drawing and forming metals.

A phosphate coating retards the amount of corrosion creep or spread.

Ferrous and Nonferrous Metals

Companies are faced with major trade-offs when running both ferrous and nonferrous metals on the same line. Maximizing salt-spray performance is difficult under these conditions. This is true for users working with multiple-metal lines (those treating zinc, aluminum, and steel parts from the same wash system), or systems treating ferrous and nonferrous metals through an iron phosphate system. Evaluate and test the substrates before equipment installation. If high corrosion protection is required, consider two pretreatment lines for the best performance.

Zinc Phosphate

Phosphate coatings are produced on ferrous and nonferrous metal surfaces and are composed of tiny crystals of iron, zinc, or manganese phosphates. The inorganic coatings produced on metal surfaces retard corrosion and promote better paint bonding. Phosphate coatings are produced after precleaning or are formed in a combination bath known as a cleaner-phosphate.

A zinc phosphate coating is crystalline and extremely adherent to the substrate.

CHECKING FOR QUALITY

To ensure a pretreatment system is performing satisfactorily, testing must be performed on the substrate. The tests are easily accomplished in a short time. Failure to routinely perform these testing procedures may allow the product to be improperly finished and sent to the customer. So regular test scheduling must take place and written documentation of the test results must be recorded.

Water-break-free Test

The water-break-free test measures whether the removal of organic soils from the substrate was successful. The test is performed by slowly pouring water onto the entire surface of a pretreated part. Watch the surface as this test is being performed. If the part is water-break free, water should not bead around any area of the part. There should be no “water breaking free” over the entire surface.

If there is water beading or breaking around in a spotty fashion, organic soils are present on the surface and repeating the pretreatment process is needed. This is a good time to see if the substrate was overly soiled or if the wash system is in need of maintenance. Never apply a topcoat over a water-break surface. There can be no adhesion longevity without a water-break-free surface.

The water-break-free test is reliable approximately 90% of the time. This test is especially useful on oily surfaces. Smut has no effect on a water-break-free test. Water breaks freely over smut areas. Deposited hard-water salts cannot be detected with a water-break test. A water-break test is also a measure of the cleanliness of the rinse water being used. (Be certain a water-break-free test is being administered with clean fresh water.) A surface under test may, indeed, be clean, but the rinse water may be dirty. Such dirty rinse water beads on a surface as if the surface were dirty (see Figure 8-2).

Generally, bath water should be dumped on a regular basis (determined by doing a water-break-free test). Even though the chemical's cleaner action is present (according to testing), the oils in the system tend to be repeatedly applied to the surface of the part. Eventually the part drags this oil to the rinse stages where it is reapplied to the surface of the part in that stage.

Unless an eductor system is built into the tank's bottom to suspend and disperse solid inorganic material into a filter system, rely on the water-break-free test to provide a rough guide as to when to change the bath. Chemical suppliers should have experience to assist a user in determining when to dump.

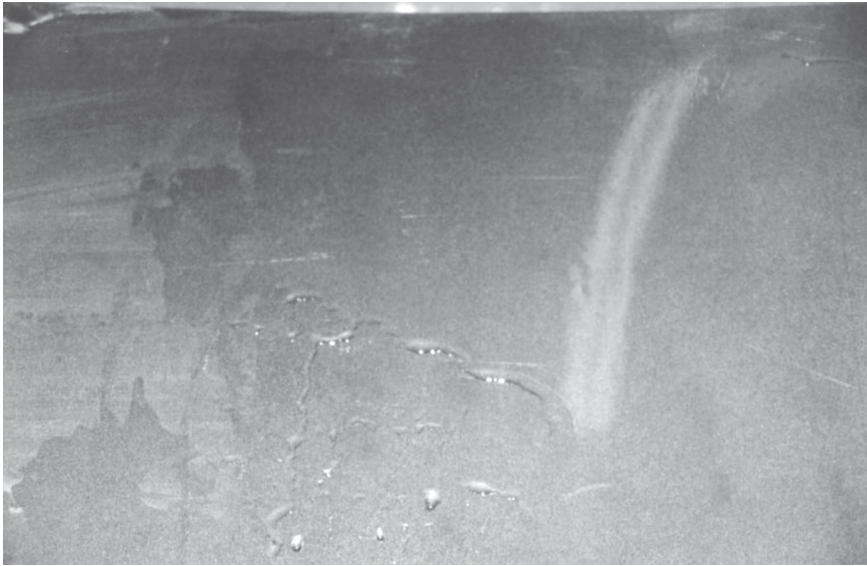


Figure 8-2. Example of improper cleaning (water is breaking around the oil).

Clean-towel Test/White-towel Test

The clean-towel test is conducted by wiping a surface with a white, or near-white, towel to determine surface cleanliness. This test generally indicates whether effective inorganic-soil removal has taken place.

After wiping the surface, a clean towel indicates the surface is clean; a dirty towel indicates a dirty surface. The clean-towel test is usually good for much of the time when the water-break-free test is invalid. Smut shows up readily with the white-towel test.

When performing the white-towel test, be certain to wipe areas that were not entirely impinged (such as the part's edge).

Tape-pull Test

In the tape-pull test, apply a clear tape to a clean, dry surface. Remove the tape and place it on a white piece of paper. The test indicates the effectiveness of inorganic-soil removal as the contrast between the tape and the paper should allow a user to easily identify remaining soils.

Tape-pull Nonferrous Test

The tape-pull nonferrous test is a quick test used in applications where finishing lines pretreat multiple metals or nonferrous castings. The steps are:

1. Apply clear tape to a flat area on a casting before the casting enters the pretreatment washer.
2. Wait until the casting exits the washer (before the dry-off stage) and then manually blow-dry the tape.
3. Remove the tape from the casting. The test provides a good, quick way to visually compare cleaned and micro-etched areas with a raw or untreated area (the untreated area was insulated from pretreatment by the tape).

UV-reflectivity/Ultraviolet Detection Test

To conduct the UV-reflectivity test, shine a calibrated source of UV radiation onto the part's surface and onto a clean surface of the identical material. The percent of UV reflected from each surface is converted to a relative number. If the relative number from the reflection of the test surface is the same as the clean surface, the test surface is clean. A lower relative number would indicate the surface under test is dirty.

Fluorescent Test

In the fluorescent test, a fluorescent dye is placed on the part prior to cleaning it. After the part is presumably cleaned, it is checked with the ultraviolet light to see if any dye remains.

Contact-angle Test

The contact-angle test is conducted when a part is dry. Drops of water measuring 0.00169 oz (0.05 mL) are placed on the part. The drops of water flatten. The diameter of the drops measures the cleanliness. The greater the droplet diameter, the cleaner the part.

Residue-pattern Test

In the residue-pattern test, a sample panel is run through a cleaning process. The panel is then placed in an oven at 120° F (49° C) for 20 minutes. The panel is removed from the oven and examined for a pattern. Evidence of a pattern indicates the presence of soil.

Acid-copper Test

The acid-copper test, also called the Neilson Test, consists of immersing the panel to be tested in an acid-copper solution. If the surface is clean, copper from the solution adheres to the panel. If the surface is soiled, the copper will not adhere. This actually is a test for the electroless plating of copper.

Scanning-electron Microscope

A scanning-electron microscope examines the panel sample. X-ray diffraction can determine the exact chemical makeup of any soil present on the surface.

Radioisotope

In the radioisotope test, a sample panel is exposed to a source of soil or oil containing radioisotopes. The panel is then cleaned and placed in a radiation detector. If radiation is present, the panel has not been cleaned properly.

ESCA-scan Test

The ESCA-scan test uses a highly ionized argon gas beam to bombard a surface. This bombardment strips the top layer of molecules on a surface and argon gas carries them away. The argon molecules are then analyzed for contaminated content with a mass-spectroscopy device.

Summary

If a user believes the washer system is functioning properly, a valid technique is to check for water-break-free surface cleanliness at the end of the washer outlet or vestibule. Inorganic surface cleanliness can be checked at the end of the dry-off oven.

Remember:

- organics = water-break-free test.
- inorganics = white-towel test.

If either test fails, the substrate needs to be recleaned or the part's adhesion and cosmetic functions will be compromised. Parts should be at an ambient temperature when being tested so adhesive from the tape does not interfere with the testing procedure.

THE VALUE OF TITRATION

Many shops do not realize the importance of the pretreatment system and do not regularly titrate it. Nor do they have a log or charting system to record test data to be analyzed. They do not have published specifications required by their chemical supplier. When this happens, the employees who are testing the bath do not have written specifications to test against, nor do they have written specifications to perform a test function. This lack of specifications means no two (or more) tests may be performed the same way. It is important for testing data to be recorded so trends can be monitored. These trends should be analyzed based on individual workers and work shifts. This is one way to analyze the system to determine if concentration levels, pH levels, or rinse water TDS are getting out of control.

Many employees are able to titrate for concentration and monitor pH and TDS levels; however, they cannot interpret the information or execute a follow-up action when the system is out of specification according to the chemical supplier.

Realistically, titration should be executed every hour, as the potential for producing reject parts starts when any mechanism in the pretreatment fails. In other words, the system produces reject parts from the time the system fails. So, the sooner the

problem is caught, the sooner it can be corrected. Washer systems need a watchful eye.

Automatic Controllers

Many companies use automatic titration and chemical addition pump devices. These are great tools to assist in production; however, baths must still be titrated manually to determine if these tools are functioning properly. Automatic tools keep a bath at pre-determined specifications. Titrator probes must be regularly (daily) cleaned to ensure satisfactory readings are taking place. The pumps usually are only for low-flow chemical additions. They work if the remainder of the system works.

Problems arise when a portion of the system fails and a large amount of chemical needs to be added into the system. Most pumps deliver a flow rate of approximately 4.5 gal/hr (17 L/hr). So if an additional 12 gal (45 L) of chemical or some pH corrector is needed in the etch tank, it would take four hours to add it. This does not take into consideration the pH lost during these four hours. So to get the bath back into specification quickly, the capability is needed to add large amounts of chemical via a hand pump. Bulk feeding a bath is never a good idea. Chemicals in baths take time to settle out and perform properly.

Concentration Levels

If the tank cannot quickly be brought back into specification, parts will be poorly pretreated.

The concentration level of the cleaner stage is approximately 2–4% by volume. A chemical representative can assist in determining the proper level and chemical makeup.

It is important that the concentration level be kept in tolerance to keep the substrate cleaning well. Lack of proper cleaning ultimately leads to adhesion problems and could contaminate other system stages.

If excessive surfactant is mistakenly added, it probably will not affect the cleaning process, but could possibly contaminate other

system stages due to carryover from stage to stage. It also wastes money.

In general, pretreatment cleaners do not remove stickers, markers, and gum. When titrating, a good practice is to check the following at each stage:

- the liquid levels of the stages to ensure the pumps do not run out of liquid;
- the floats to ensure the liquid levels remain constant or permit overflowing;
- the temperature gages to ensure adequate temperature is being maintained;
- each zone should be spraying and the impingement pressure gage should be checked for the set pressure; and
- part drainage or cupping action should be done at every stage.

Cheat Sheets

A *cheat sheet* (Figure 8-3) is a document (usually a single page) that specifies predetermined chemical additions according to a manufacturer's system and titration. It is a quick reference tool used by the operator to determine (with close accuracy) the amount of chemicals to be added to the bath to return it to specification. By adding the appropriate chemicals with the aid of the cheat sheet, a user cuts labor time, because all titrate is added at once. Otherwise, continual titrations would be necessary.

Maintaining Meters, Logs, and Specifications

Titration equipment needs to be calibrated prior to testing. TDS cups can be tested with established conductivity-standardizing solutions. With ISO 9000 requirements, companies must have accurate calibration records. A pH meter can be checked using established standard buffer solutions.

It is important to keep accurate records and logs of both TDS/conductivity and pH meters data. The information to be recorded is the following:

- date;
- bottle number;
- expiration date;
- μmho ;
- degree of accuracy;
- remarks; and
- approval signatures.

Chemical Additions Cheat Sheet					
Stage 1 = 2,638 gal $2,638 \times 0.025 = 66.0$ gal to fully charge the cleaner Concentration = 2.4–2.6			Stage 3 = 1,419 gal $1,419 \times 0.025 = 36.0$ gal to fully charge the etch tank Concentration = 2.4–2.6		
%	gal of cleaner	add gal	%	gal of etch	add gal
2.5	= 66.0		2.5	= 36.0	
2.4	= 64.0	3.0	2.4	= 34.0	2.0
2.3	= 61.0	6.0	2.3	= 33.0	4.0
2.2	= 59.0	8.0	2.2	= 32.0	5.0
2.1	= 56.0	11.0	2.1	= 30.0	7.0
2.0	= 53.0	14.0	2.0	= 29.0	8.0
1.9	= 50.0	16.0	1.9	= 27.0	9.0
1.8	= 48.0	19.0	1.8	= 26.0	11.0
1.7	= 45.0	22.0	1.7	= 25.0	12.0
1.6	= 43.0	24.0	1.6	= 23.0	14.0
1.5	= 40.0	27.0	1.5	= 22.0	15.0
1.4	= 37.0	29.0	1.4	= 20.0	17.0
1.3	= 35.0	32.0	1.3	= 19.0	18.0
1.2	= 32.0	35.0	1.2	= 17.0	19.0
1.1	= 29.0	37.0	1.1	= 16.0	21.0
1.0	= 27.0	40.0	1.0	= 15.0	22.0
.9	= 24.0	43.0	.9	= 13.0	24.0
Cheat sheets should be posted in the titration area. 1 gal = 3.785 L					

Figure 8-3. Chemical additions cheat sheet.

When using TDS cups, remember to rinse the holding cell at least three times to ensure no residual chemicals or contamination affects the reading.

Checking equipment for two-point calibration is a good backup to ensure accuracy. Make sure the TDS cell has an automatic temperature compensator built in, as temperatures play a huge part in determining TDS accuracy. The warmer the liquid, the higher the TDS reading.

The purposes of posting titration levels are:

- to give performance specifications;
- to eliminate a variety of individualized tests;
- so that employees can monitor and maintain levels; and
- to allow the monitoring of concentration levels or rinse water TDS levels.

Proper maintenance of the washer system means checking for:

- bath life;
- plugged nozzles;
- nozzle settings (1 o'clock/7 o'clock positions improve impingement performance and extend cleaning time for each nozzle);
- the condition of zip-tip or plastic-variable, angle-type nozzles;
- misaligned nozzles;
- poor-impingement pressures;
- improper line speeds; and
- improper chemical concentration and pH levels, etc.

Chemical Concentration

Through testing, a supplier provides a recommended concentration range, typically 2–4 oz/gal (15.6–31.2 mL/L) or 1–3% by volume. Maintaining the chemical concentration through titration is critical to the development of the phosphate coating. Coating weights range from 0.0011–0.0025 oz (31–71 mg). Substantially lower or higher coating weights can be detrimental to powder bonding, corrosion resistance, or both.

The pH of solution. Control of pH is essential for phosphatizing. The pH value is not an accurate indicator of concentration.

Rather, pH is the means for fine-tuning the concentration of an iron phosphate bath.

Line speed and temperature. Overall solution contact time remains fixed in reference to line speed.

Follow the supplier's recommendations for temperature control of an iron phosphate bath. As with concentration control, temperature control impacts the development of phosphate coating weights.

DESCALING PROCEDURE

The following is a general description of the descaling procedure. Contact a supplier for specific needs.

1. While the solution is hot and static, overflow some liquid to displace the surface oils and allow the automatic skimmer to remove as much free oil as possible.
2. Drain the solution from the tank.
3. Flush any solids and/or sludge and remove for disposal.
4. Refill the tank with water.
5. Add a sufficient amount of highly caustic, high chelate alkaline descaler material to reach 4–6 oz/gal (31.3–46.9 mL/L).
6. Heat the solution and circulate it for one to two hours at maximum obtainable heat. Low-foam detergent may be added at a volume of 0.5–1.0% to help displace oils.
7. Allow the solution to remain static for 20–30 minutes.
8. Overflow the solution to displace any surface oils or allow the automatic oil skimmer to remove any residual oils.
9. Drain the solution from the tank.
10. Flush any solids and/or sludge and remove for disposal.
11. Remove the riser nozzles.
12. Fill the tank two-thirds full with cold water.
13. Add a volume of 10% descaling acid (muriatic). To minimize fuming to the air and plant environment, use a low-volume hand pump with the discharge line immersed below the liquid level in the tank.
14. Circulate and heat the solution to 120° F (49° C) for one to two hours.

15. Drain the solution from the tank.
16. Flush any solids and/or sludge and remove for disposal.
17. Inspect, clean, and replace the nozzles to the risers.
18. Refill the tank with fresh water and heat it.
19. Add a volume of 0.1–1.0% phosphate. Circulate the washer for 5–10 minutes.
20. Drain the solution from the tank.
21. Flush any solids and/or sludge and remove for disposal.
22. Fill the tank with water to the operating level.
23. Charge the tank with the processing product.
24. Consider drain solution as an effluent and dispose of properly.

Common Mistakes

Generally, most mistakes are simple errors caused by operators. Vendors constantly are called into the shop to fix simple errors when the operators should be trained to identify and fix the problems. Common mistakes include:

- improper chemicals for the intended purpose;
- improper hanging configuration;
- improper line speed;
- improper concentration levels;
- improper pH levels;
- improper temperatures;
- improper rinsing;
- improper impingement pressure;
- oil-saturated baths;
- improperly aligned and plugged nozzles;
- washers needing descaling;
- stopping the washer during breaks; and
- poor record keeping.

Improper Chemicals for the Intended Purpose

Chemicals should be developed for the type of ware to be cleaned. This means if different metals and sufficiently tougher-to-remove soils are encountered, a user may need to alter the chemical.

Improper Hanging Configuration

The hanging pattern can drastically affect the washer's impingement action. Make sure nozzles can "see" the surface to be cleaned. If impingement cannot reach an area of the ware, then the area is not thoroughly cleaned.

Improper Line Speed

The washer system should be designed for the ware to be cleaned for at least 60–90 seconds (preferably 90 seconds). The time changes if the ware is larger and needs more cleaning (but generally this is the accepted practice).

Improper Concentration Levels

If the concentration levels drop, less cleansing will occur. Make sure to keep the concentration at proper level.

Improper pH Levels

If pH levels drop, the probable result is a nonuniform etch and/or conversion coating. This means less adhesion.

Improper Temperatures

The proper temperatures are needed to assist surfactants or wetting agents in removing soils. Many soils will not be removed without the appropriate amount of heat.

Improper Rinsing

The rinse water must be clean to rinse residual contamination from the substrate. If rinse water is contaminated, so is the substrate.

Improper Impingement Pressure

Impingement pressure must be sufficient to remove soils. A user should be able to regulate this pressure to correspond to the part's hanging configuration and weight. Nozzle sizes can be adjusted to suit the substrate's profile. Check with a chemical representative for advice.

Oil-saturated Baths

The undesirable result of running a ware through an oil-saturated bath will show up in the water-break-free test. If the test is not being conducted to find oil saturation, the result will be diminished adhesion. If the bath needs changing, employees or operators should be encouraged to do this task. Trying to get jobs done on a timeline is no excuse for failing to change the bath.

Improperly Aligned and Plugged Nozzles

Plugged nozzles are a common problem. Most nozzles start plugging at the outside ends of each riser. Heavy soils are carried to the end of the riser because the pump pressure is high. Once the nozzle's end becomes plugged, the nozzle next in line becomes the main exit where the dirt/soil begin to clog. (The easiest path is the path the water takes.) When the dirt/soil reaches the nozzle, it can become trapped. Once trapped, each previous (and consecutive) nozzle begins the same plugging action. As plugging occurs, the substrate is washed for a diminished amount of time within that stage. (Remember: the ware must remain in each stage for a required amount of time.)

Washers Needing Descaling

Many washers need descaling. If scale has built up on the washer, the added chemical will be neutralized. In this case, the scale on the walls and ceiling will drop on the ware or in the tank, and then end up in the nozzles. Remember that 1/8–1/4 in. (3.2–6.4

mm) of scale on a burner tube is equal to approximately 20% loss of efficiency.

Stopping the Washer During Breaks

Many employees stop production to take breaks. Production stoppage creates a problem, as a washer system is designed for the ware to remain a certain amount of time in a particular stage. If timing is not carefully controlled (including an accounting of break times), there will be a detrimental effect on cleanliness or adhesion. The washer should be emptied during shutdowns.

It is worth noting that too much phosphate on the surface results in a white phosphate residue chemical. This white phosphate residue does not accept paint. Flash rusting also can occur at a rapid rate in the rinse stages. This undesirable process can take place even if the washer is off.

Poor Record Keeping

Keep records. This is the best method to track problems. If a trend starts to develop, appropriate actions can be taken. The records can report if the operator's titrating is identical or different.

As a rule, follow the procedures recommended by the pH-meter manufacturer and keep in mind the helpful operating techniques provided in this text. The frequency of calibration is a function of the electrode, the pH meter, and solutions the electrode is exposed to. The electrode and meter should always be calibrated together; this, in addition to the operator's experience, should be taken into account when determining calibration frequency.

When pH readings are made infrequently (for example, several days apart), the electrode can be stored simply by placing it in its soaker bottle. First, slide the cap onto the electrode, then the o-ring; then, insert the electrode into the bottle and firmly tighten the cap. If the solution bottle is missing, fill the bottle with pH 4.00 buffer.

Electrode Cleaning

Coating of the pH bulb can lead to erroneous readings, including shortened life span of the pH probe. The types of coating determine the cleaning technique. Soft coatings can be removed by vigorously stirring or with a squirt bottle. Organic chemical or hard coatings should be cleaned as abrasion can lead to permanent damage. If cleaning does not restore performance, recondition may be attempted.

In testing for solution pH:

1. Turn on the pH meter.
2. Take the temperature of the known pH sample, 4.00.
3. Set the pH meter temperature to that of the known pH sample.
4. Insert the probe into the 4.00 solution.
5. Turn the pH dial to 4.00 to set the standard.
6. Take the temperature of the solution to be tested and readjust the pH temperature dial to compensate for the difference.
7. Test the solution.

It must be noted that although pH paper-test strips are good indicators of pH, a pH meter is more accurate.

Titration Procedure

A typical titration procedure for a five-stage washer (other methods are available depending on vendor) is as follows.

Stage-one procedure.

1. Take a 1.7 oz (50 mL) sample of solution with the pipette and place it in the flask.
2. Add five drops of P#12 (phenolphthalein) to the solution.
3. Carefully add solution 0.1N acid to the mixture in the flask until the pink color disappears.
4. From the solution 0.1N acid used, read the graph provided by the supplier to the inclined line. Then go to the left vertical column and read off the concentration of chemical in the original solution in percentage by volume.

Some companies do not use graphs, but use a reference chart instead.

Stage-three procedure.

1. Take a 0.8 oz (25 mL) sample of the solution with the graduated cylinder or pipette and place it in the flask.
2. Fill the flask approximately one-third full of water and add five drops of the indicator phenolphthalein to the solution. No change will be seen.
3. Carefully add solution 0.1N sodium hydroxide to the mixture in the flask until the pink color disappears.
4. From the solution 0.1N sodium hydroxide used, read up the graph provided by the supplier to the inclined line. Then, go to the left vertical column and read off the concentration of the chemical in the original solution in percentage by volume.

CHECKING FOR TOTAL DISSOLVED SOLIDS

To check for the amount of suspended particulate in a solution, take a sample of the solution in a pipette and pour it into the holding reservoir of the TDS test tool. By pushing the test button, the meter will read in the 1,000 scale, and it will not read past 5,000. A user also can turn to the 100 scale to read smaller amounts of particulate more accurately.

Single-point Calibration

To conduct a single-point calibration on a pH meter:

1. Connect the pH electrode to the instrument and remove the protective cap from the electrode.
2. Rinse the pH electrode with distilled water or reverse osmosis (RO) water and immerse it in pH buffer 7.00.
3. Turn on the instrument by setting the three-position rocker switch to the ON position.
4. Set the “temperature” control to the temperature of the pH buffer.
5. Adjust the “standardize” control to read the buffer value corresponding to the buffer temperature.

6. Remove the pH electrode from the pH buffer solution.
7. Rinse the electrode with distilled water or RO water. The pH meter is now calibrated and ready for use.

Two-point Calibration

To conduct a two-point calibration on a pH meter:

1. Connect the pH electrode to the instrument and remove the protective cap from the electrode.
2. Rinse the pH electrode with distilled water or RO water and immerse it in pH buffer 7.00.
3. Turn on the instrument by setting the rocker switch to the ON position.
4. Set the “temperature” control to that of the pH buffer.
5. Adjust the “standardize” control to read the buffer value corresponding to the buffer temperature.
6. Remove the pH electrode from the pH buffer solution.
7. Rinse the electrode with distilled or RO water.
8. Immerse the electrode in pH buffer 4.00.
9. Set the “temperature” control to the temperature of the buffer 4.00.
10. Allow sufficient time for the buffer electrode to stabilize. Adjust the “slope” control of the instrument to read the buffer value corresponding to the buffer temperature.
11. Remove the pH electrode from the buffer solution.
12. Rinse with distilled or RO water. The pH meter is now calibrated and ready to use.

TDS/Conductivity Test Procedures

The TDS/conductivity test procedure is as follows:

1. Rinse the cell cup three times with the sample of the solution to be tested.
2. Select the anticipated conductivity range using the four-position switch at the front of the meter: use 10 for conductivity below 50 μmho , 100 for conductivity between 50 and 500 μmho , and 1,000 for conductivity between 500 and 5,000 μmho .

3. Push the button at least three times to substantiate a meter reading as it takes a few seconds to standardize.

PHOSPHATE COATING WEIGHTS ON IRON AND STEEL

To determine the phosphate coating weights on iron and steel, follow this procedure:

1. Cut the phosphated specimen to dimensions weighable on an analytical balance, such as a 3 in. $\times$ 3 in. (7.62 cm $\times$ 7.62 cm) piece of metal.
2. Immerse the specimen in acetone or a volatile solvent to remove finger oil soils. Dry the specimen.
3. Carefully weigh the specimen on an analytical balance.
4. The phosphate coating should be completely removed after immersing the specimen in a 5% chromic acid solution at 165° F (74° C) for 15 minutes, followed by rinsing, drying, and weighing. This procedure should be continued until a constant weight is attained.
5. Reweigh the panel immediately.

To calculate the coating weight, use the following equation:

$$(C_w) = (I_w - F_w) \times T_s \quad (8-1)$$

where:

C_w = coating weight, oz/ft² (mg/cm²)

I_w = initial weight, oz (grams)

F_w = final weight, oz (grams)

T_s = total surface area, length $\times$ width $\times$ 2 (for both sides), in.² (cm²)

Avoiding Pretreatment Failure

In the field of powder coating, pretreatment is a complex process. Coating failures related to inadequate pretreatment rarely have a single, obvious cause. Instead, several small deviations from the chemical supplier's recommendations for controlling chemical solution quality and/or from the equipment supplier's recommendations for maintaining the equipment cause failures. For the best process results, powder-coating users should emphasize:

- how to control the process;
- selection and use of the right chemicals; and
- design and maintenance of the equipment.

Powder's failure to permanently adhere to a part may occur immediately after coating and curing, a few hours after, or several months later. Most powder coaters comment: "If I produce a reject or a product not meeting the minimum standards specified, I'd rather catch it immediately, find the cause, and correct the problem, and not have my customer catch it for me." Unfortunately, this is not always possible.

When a pretreatment system operates "out of control," there is no way to predict if—or when—it will fail to perform adequately. (A system approaches the state of being "out of control" when proper attention is not paid to quality of the pretreatment solutions or to the physical condition of the equipment.)

The durable finish characterizing a cured powder coating can make it difficult for finishers to detect coating failures. When

powder is applied over a properly pretreated part, its great cohesiveness provides excellent adhesion and corrosion properties. But powder's cohesiveness also may hide poor pretreatment initially, preventing the coating failure from being noticed until after the customer buys the product. To avoid this, get control of the pretreatment process. Make sure to follow the chemical supplier's recommendations regarding the various chemical solutions. The solutions must be at the temperature and concentrations recommended and the equipment must be maintained for optimal performance. For quality, nothing beats consistent control, well-chosen chemicals used correctly, and well-designed, properly functioning equipment.

OPERATING AND MAINTENANCE MANUALS

It is impossible to over-emphasize the importance of two items in troubleshooting on-line pretreatment problems:

- the operating manual, and
- the maintenance manual.

A chemical vendor can supply both of these items. They provide a baseline for controlling pretreatment chemicals and for maintaining the mechanical power washer.

The Operating Manual

The bulk of the operating manual provides an overview of the washer, the chemicals specified for each stage, and recommendations for controlling the quality of each chemical and rinse stage. The operating manual usually also includes the following:

- chemical product fact sheet;
- current material safety data sheet;
- the format for a daily log;
- tank labels;
- descaling procedures;
- titration information;
- safety information; and
- effluent neutralization procedures.

The Maintenance Manual

The mechanical washer maintenance manual contains the maintenance procedures that the equipment manufacturer and the chemical vendor agree upon. The procedures keep the pretreatment equipment operating efficiently. The topics covered usually include:

- recommendations on nozzle size and type for each stage;
- the routine for checking, cleaning, and replacing nozzles;
- recommendations for water levels and information on operating and maintaining fill mechanisms;
- procedures for screen cleaning;
- pressure and temperature recommendations for each stage;
- dump and recharge schedules;
- oil and lubrication information for pumps, motors, and mono-rails;
- information on maintaining the washer exhaust system; and
- maintenance log sheets for noting the data gathered from daily, weekly, and monthly inspections and corrective actions.

Proper training and consistent use of the two manuals decreases the likelihood that the pretreatment process will go out of control, creating a situation requiring troubleshooting. Unfortunately, loss of process control is a real-world occurrence, and there are times when a troubleshooting guide is necessary. Table 9-1 does not solve the problems of every pretreatment system. However, it provides a starting point for action when the pretreatment line produces parts unacceptable for powder coating.

Pretreatment Chemical Vendors

What services can pretreatment chemical vendors provide to you? Chemical vendors can be valuable assets. The account manager knows what chemicals to recommend for a product and can help set up an appropriate titration schedule. The account manager can bring the customer's parts to a lab and test different chemistries on them. The vendor can apply topcoats on parts and test for phosphate weight as well as for cyclic performance.

Table 9-1. Troubleshooting guide for three- and five-stage iron phosphate systems

Problem	Cause	Solution
Poor cleaning	Variables such as chemical concentration, pH, process time, or temperature not at recommended levels	Bring variables to recommended levels
	Spray nozzles blocked or misaligned	Check for condition of nozzles and clean, repair, or replace as necessary
	Change in soil composition	Use detergent additive for better wetting; increase temperature of cleaning stage if soil is determined to be heat sensitive or contains waxes
	Good cleaning but poor phosphate development; light phosphate coating and low pH, producing pickling of metal substrate	Bring phosphate solution up to recommended level; increase pH if necessary
Flash rusting	Time to complete dry off too long or dry-off temperature too low	Reduce time needed to complete dry off by raising solution temperature in last stage; use fans or blowers prior to dry off
	Low, recessed areas on parts retain excessive moisture	Rerack parts to promote proper moisture runoff
	Contaminated rinses; stage-to-stage overspray	Dump, clean, and recharge rinse stages; increase overflow; check nozzle direction for overspray

Table 9-1. (continued)

Problem	Cause	Solution
Water spotting	Contaminated final rinse	Use low concentration of detergent additive in last stage (this may be detrimental to salt spray results)
	Poor raw water quality	Check total dissolved solids (TDS) in rinse tank; dump and clean rinse tanks; or increase overflow rate
Solids drip line	Contaminated final rinse	Compare TDS of rinse and raw water; dump and recharge final rinse to reduce TDS; reposition parts to minimize solids drip line; use directed air blow off
Insufficient phosphate coating	Phosphate concentration too low or pH too high	Add phosphating material to attain proper concentration or lower pH with pH-acid additive
	Contact time too short; workpiece too dirty; and phosphatizing time too short	Raise temperature; preclean parts; or use detergent additive
	Temperature too low	Raise temperature to recommended level
Mottling	In five-stage system, pH too low	Adjust pH to recommended level
	In three-stage system, more easily cleaned areas develop heavier phosphate coating; irregular spray causes mottling	Employ alkaline precleaning; control pH of phosphatizing stage by increasing or decreasing operating pH and acidity

Table 9-1. (continued)

Problem	Cause	Solution
Powdering	Excessively high pH	Use pH-acid additive to bring to desired range
	Excessive sludge in bath	Remove sludge, renew bath, or improve rinsing
	Phosphate concentration too high	Dilute phosphatizing solution to proper concentration
	Dry-off temperature too high	Maintain dry-off temperature below 300° F (149 °C)
	Chemical solutions allowed to dry between stages; line allowed to stop; insufficient rinsing	Install misting nozzles between stages; prevent line stoppages; check TDS of rinses and final rinse
Smut and inorganic soot	pH too high	Lower pH, phosphate, or cleaner-phosphate to be more reactive to smut
	Poor cleaning	Bring cleaner concentration up to recommended level
	Deficient spray pattern; insufficient impingement	Check condition of washer nozzles; ensure proper impingement
	Poor quality steel; improper storage of steel	Prequalify incoming steel; store steel correctly—indoors and away from plating lines, for example
	Poorly regulated dry-off combustion leaves residue	Check for proper ignition and combustion; check air-to-fuel ratio

Table 9-1. (continued)

Problem	Cause	Solution
Poor adhesion on nonferrous casting	Poor cleaning	Check that cleaning solution is producing a surface free of water breaks
	Insufficient etch	Check for sufficient etch in cleaning and/or phosphatizing stage; check nozzles for coverage and impingement; check that chemicals are at recommended levels
	Change in soil composition or aging of soil	Check for changes in die lubricant
Outgassing on nonferrous casting	Casting too porous	Check for casting change
	Aggressive chemical attack	Check that chemicals are at recommended levels
	Contaminants retained in casting	Pre-bake casting or raise cleaning temperature
Oil bleed out	Soil trapped in metal	Preclean metal before fabricating
	Change in amount of soil load	Reduce soil amount
	Change in soil composition	Change to lighter weight soil
	Pretreatment variables out of control	Recheck all process variables, particularly temperatures If oil bleed out continues, pre-bake parts to fluidize soil

The account manager monitors an account to insure satisfactory performance is being achieved. He or she checks the system and develops a performance history of the system. The account manager recommends any required action. Remember, the only way to tell if the system is really working is to send the finished sample to the lab for destructive testing.

Pretreatment Tips

Some added tips for pretreatment include:

- Do not let properly prepared parts sit for extended periods of time, especially if the area has uncontrolled climates where oxidation or contamination could occur.
- Pretreatment for successful powder coating means consistently providing a totally clean and dry, thoroughly rinsed, conversion-coated product to the spray booth. Control of the pretreatment system is critical to maintaining the product's consistent quality. In fact, cleaning is the single most important step in ensuring a successful powder operation.
- The powder coater's ability to produce a high-quality finished product consistently is maximized when the powder coating supplier, the wash system, and the pretreatment chemicals work together.
- To be successful, evaluate the soils and substrates being handled, determine the source and quality of the water in use, and choose the right surface preparation chemistry. The necessary training and equipment maintenance procedures must also be performed.
- In pretreatment, the mechanical quality of the pretreatment equipment and the chemical quality of the pretreatment solutions are both important. Both require daily inspection and maintenance to function at the optimal levels that the suppliers intend.
- The development of system maintenance procedures and the education of line personnel are the supplier's responsibility. Ensuring the proper procedures are performed and recorded daily is the ultimate responsibility, however, of the customer. Customers must exercise the responsibility diligently to obtain the highest quality powder coating.

Equipment Hoppers and Feeders

Parts are powder coated through electrostatic spray or immersion into an electrostatically or nonelectrostatically charged fluidized bed of powder. Electrostatic dip beds are rare and are usually small, as it could be unsafe to electrically charge a large mass of powder. In addition to electrostatic dip beds, industry uses non-electrostatic dip beds. With these dip beds, the hot parts enter the bed and powder suspended as particulates melts onto the parts. Parts must have certain geometric figures, as an electrostatic charge does not help wrap the powder to the parts. This method works well with flat surfaces or like materials as they lack areas that prohibit the powder from coating and fusing to the part. There is little powder control. Anytime a part is heated to get paint to stick to it, the ability to apply powder at a controlled and reasonable rate is lost.

By contrast, industry widely applies powder coating by spraying the powder. The method is versatile and provides better control over coating thickness.

SPRAYING POWDER

In the process of spraying powder:

1. Powder is poured into a holding hopper and onto a fluidizing membrane. The fluidizing membrane is a plastic membrane near the bottom of the hopper base.

2. Air is introduced under this fluidizing membrane.
3. Pressure pushes the air through the membrane's microscopic openings upward into the powder itself.

The powder appears to boil and looks to be a fluid. Fluidization allows powder coatings to be easily transferred from the hopper to the gun with uniformity and consistency. It also preconditions the powder before it reaches the gun. Any powder clumps or agglomerations are broken up at this stage of the process, leaving the powder material with a smoother flowability consistency.

Regulated pressure distribution of air through the membrane ensures proper fluidizing. The container's mechanical vibration sometimes enhances fluidization and reduces the possibility of air channeling and powder clumps.

Fluidized Beds

Figure 10-1 shows a typical feed hopper. A fluidized feed hopper needs a clean and dry air supply (typically less than 0.1 PPM oil and a dewpoint below 35° F [2° C]). Clean, dry air is a must. Oil, water, or pipe scale contaminants within the air supply result in blocking—and possibly rupturing—the porous membrane, resulting in an uneven fluidizing distribution, ultimately affecting the part's finish. Powder material contamination is a possibility when moist air is used. Fisheyes also can occur when moisture or oil contaminates the membrane. Problems with fluidization or in spray application can be traced to the hopper.

Some tips on using fluidized bed hoppers include:

- A properly fluidized bed of powder boils gently and evenly. The powder looks as if it is simmering. If geysers or boiling on one side appear, check the amount of powder in the hopper and try to mechanically get it boiling. If this is unsuccessful, empty the powder from the hopper and disassemble the membrane from the hopper. Geysers form when the air escapes through channels to the surface and no powder is moved. When geysers occur, the powder to the pumps is scarce and/or puffing at the gun occurs as there is no fluidized powder around the pickup tube. Instead it attempts to pick up

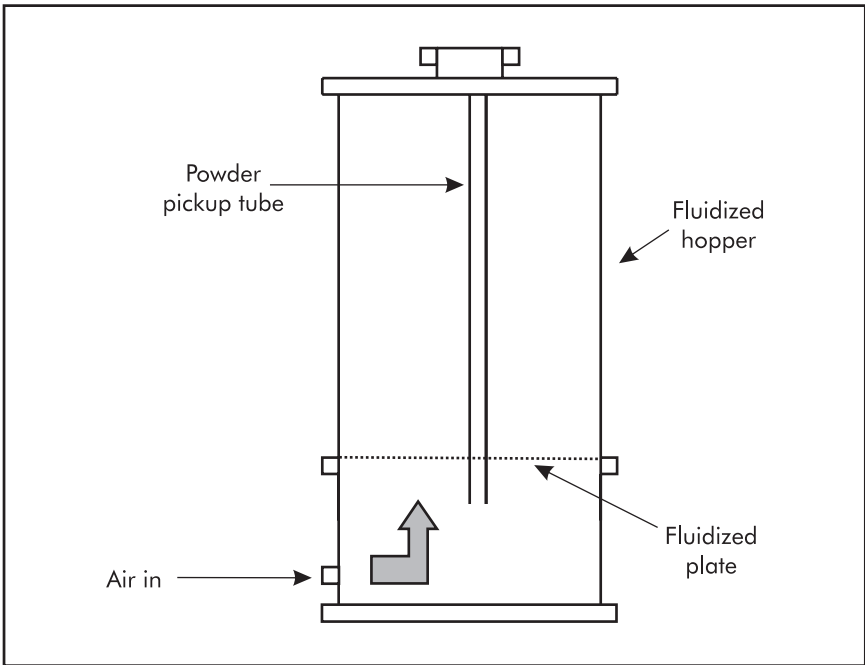


Figure 10-1. Typical feed hopper.

“dead powder” resulting in inconsistent flow from the powder pump(s) (see Figure 10-2).

- Visually inspect the top of the membrane for signs of scratches or gouging from foreign objects used to start fluidizing the powder.
- Only plastic materials should be used to assist the fluid hopper when powder is “dead.”
- Check the bottom of the membrane for signs of oil or moisture.
- If oil is introduced onto the fluidizing membrane’s surface, air pressure forces the oil into the membrane, resulting in the membrane needing replacement. Before replacing the membrane, find the oil and moisture source and repair the problem.
- Air used for powder coating should be sent through a drier and filter system to ensure it is dry and free of oil.
- Every powder coating material resin possesses its own peculiar fluidization characteristics. The amount of air required

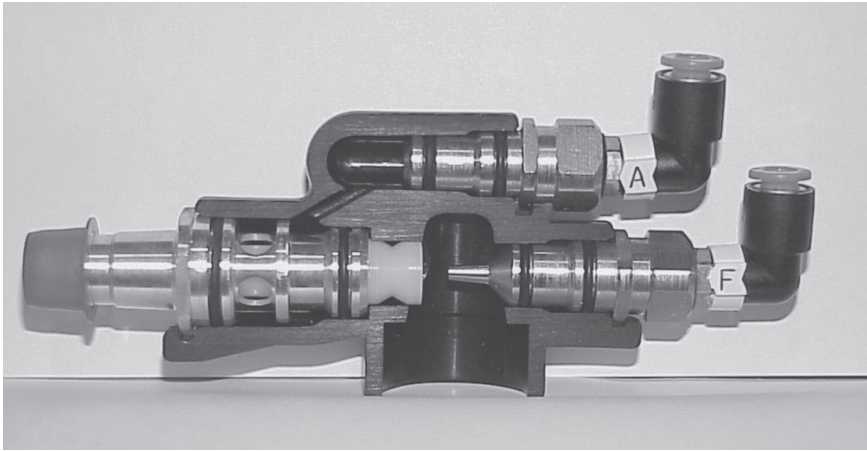


Figure 10-2. Typical venturi pump.

per cubic foot, density of the bed, and physical conditions at the top and bottom strata vary with the particular formula. It is important that the bed be completely aerated from top to bottom. Hoppers must be vented to reduce pressure buildup.

- A layer of “dead,” dense, or compacted powder, located directly above the membrane may lead to progressive stratification, ultimately affecting the coating results achieved at the dipping sector. For this reason, it is important to make powder additions to the bed in frequent, low-quantity increments.

Bed Density

The density of the porous bed is dependent upon the nature of the powder and the operating conditions.

The density of a particular powder may be measured, of course, by its weight per volume. That measure is, however, not sufficient to determine how it fluidizes. The best evaluation of density in an operating bed results from measuring the percentage of expansion as static powder moves to an elevated porous fluidized condition. The rule is that powder rises to twice its height after fluidization. So, a feed hopper filled to more than a 50% level, and fluidized, probably would reach the top of the hopper and overflow.

PARTICLE DISTRIBUTION

Since fluidizable powdered resins, either thermosetting or thermoplastic, exhibit a particle size distribution resembling a bell-shaped curve, it is significant that the bed's composition changes during operation. There is selectivity in deposition; the fines are removed from the bed at a higher rate than the coarse particles.

A pickup tube inside the feed hopper runs to a pump. This pump enables and regulates the amount of powder transferred to the powder gun. The powder pump can be referred to as an *injector* or *venturi pump*. There is normally one pump for one gun. The pump delivers the powder from the feed hopper to the spray gun in a controlled, consistent, and uniform flow. Figure 10-2 shows a typical venturi pump. Pumps apply the venturi principle. That is, air is passed over a venturi throat and powder is drawn up a pickup tube and into the pump where it is passed onto the spray gun through the transfer hose. A hose running from this feed hopper to the gun (called a *transfer hose*) transfers the powder to the gun where it is electrostatically charged. A control panel monitors and controls the powder-flow rate and velocity to the gun. The feed tube's top connects the pump to the powder supply. When high-velocity air is passed across the feed tube's top, it enters the pump chamber and the low-pressure zone created causes a vacuum. The vacuum, in turn, causes the powder to be drawn into the pump chamber through the pickup tube. Once the powder reaches the pump, a secondary air source helps control and regulate the powder's delivery to the gun. This secondary air is sometimes called atomizing air, conveying air, or diffusing air. There is normally one pump for one gun. The parts that wear in most pumps vary depending on the equipment; however, the most widely worn part is the venturi throat.

Pump parts exposed to high-velocity powder streams are prone to wear and impact fusion. In impact fusion (a sintering process), the powder grains become fused in hard, tightly bonded deposits on the walls of powder passages. This results in blockage and reduced flow rates. The tendency to impact fusion is related to the velocity of the powder, the directness of impact, wall material, and the specific powder's nature.

As previously mentioned, venturi throats are the most frequently worn. Usually, these throats are made from Teflon[®] and

designed to wear rather than build heat causing powder agglomeration and/or fusing. Other materials that are available in venturi throats are Tivar[®], glass-filled Teflon[®], stainless steel, and Delron[®]. Some throat holders contain plastic wear tubes to prevent powder from wearing holes into the aluminum housing.

It is important to continually check for pump-part wear. Powder is abrasive in nature, causing plastic parts to wear out. Once the throat elongates or opens in diameter, more air is needed to keep the powder consistently flowing to the spray gun. If the diameter gets too large, air races through without an even, consistent powder flow and surging and puffing occurs. This condition develops slowly. An inability to maintain production is usually the first sign that powder is not being evenly distributed. As a remedy, many users increase the air velocity, which results in less powder being drawn into the pickup tube. The drawn powder agglomerates at the venturi.

A powder-feed hopper provides sufficient material to one or many electrostatic spray guns located several feet away. Powder-feed hoppers are available in many sizes. Selection depends on the application, number of guns to be supplied, and the volume of powder to be sprayed over a specified time. Generally, these feed hoppers are made of sheet metal and placed near the powder-collection hoppers.

Once the powder reaches the gun, it passes through a deflector. The deflector is responsible for the size and shape of the powder cloud as it exits the spray gun. This cloud is an important feature of the entire application system. The proper cloud allows the powder to be applied to the part easily and quickly. There are numerous deflector sizes and configurations.

An electrode is a small, negatively charged metal pin near the deflector. It creates an electronic field known as a *corona*. As the powder passes around the deflector and through the *corona* field, it takes on a charge. Controlling and adjusting the kilovolts and/or amps determines the powder's rate of charge.

Vibratory Box-feed Hoppers

Vibratory box-feed hoppers feed powder directly from the powder box (as shown in Figure 10-3). This system sets up quickly,

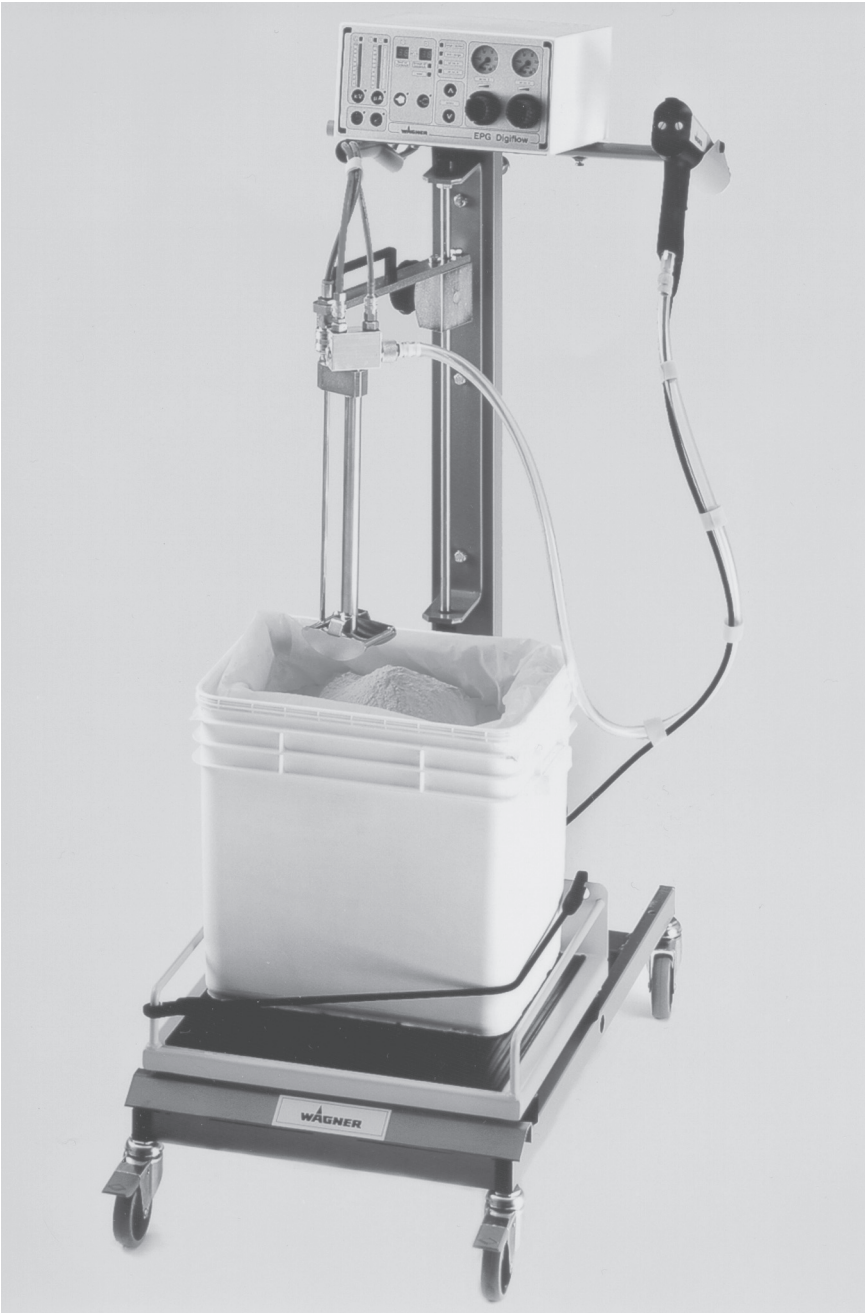


Figure 10-3. Vibratory box-feed hopper. (Courtesy Wagner)

but the lack of proper fluidization can cause pulsing at the gun. The pickup tube tends to suck the powder from around the tube empty and pushes air to the gun until more powder vibrates and falls around the pickup tube. These feeders are beneficial for small shops or small batch operations.

Sieving Devices

Generally, equipment manufacturers and material suppliers recommend sieves. Vibratory and rotary sieves are available in a variety of throughput capacity ranges. The size of the screen mesh used in the application affects throughput capacity. The mesh of the screen can lower the throughput capacity of the sieve (all other factors being equal). The choice of screen depends on the powder-particle size, the size distribution of the powder, the nature of the contamination found in the powder, and the required degree of cleanliness. It is also important that powder be sieved at an even rate. By forcing powder through a sieve faster than the sieve can screen the material, the powder builds and creates heat, causing fusing within the sieve screen and housing.

Screen-mesh sizes from 60–140 openings per square inch are commonly found in powder-coating system sieves. Table 10-1 shows typical data for sieve screens. The sieve maker or equipment supplier should be contacted to discuss the correct screen size for each powder type. Smooth powders generally require different screen sizes than textured powders or clear acrylics. A screen size that is too fine wastes powder and does not clean contaminants out of the powder.

At times, hair can pass through the sieve screens as it can turn on end and because it is slender. Powder fines, box fibers, cartridge fibers and other contaminants can also pass through a sieve.

Used with feeder units, sieving devices screen any dirt, clumps of powder, or other debris, and condition the powder prior to spraying. These sieving devices can be mounted directly to or above the feeder unit to facilitate powder flow within the closed loop of powder delivery, spray, and recovery. Sieving devices mounted on the feeder unit must be kept free of debris and screens clear of powder buildup. Proper venting of the sieve is critical as performance deteriorates if there is much differential pressure across the screen.

Table 10-1. Typical data for sieve screens

U.S. Mesh Size	Mesh Opening* in. (μm)	Open Area	Mesh Count per in.
30	0.0232 (590)	42%	28
35	0.0197 (500)	39%	32
40	0.0165 (420)	38%	37
45	0.0138 (350)	36%	44
50	0.0108 (275)	33%	54
60	0.0098 (250)	37%	62
70	0.0083 (211)	46%	82
80	0.0073 (185)	37%	81
100	0.0059 (149)	38%	104
120	0.0049 (125)	37%	123
140	0.0041 (105)	36%	145

*U.S. Particle Size

Vibratory sieves. A vibratory sieve has a screen stretched over a drum head. The screen vibrates against the powder and the powder breaks up and spreads across the screen, allowing the smaller particles to fall into the collection area.

HOSES

The transfer hose is an often overlooked component of the powder-paint operation. Hose routing should take as direct a path as possible. Extra length of hosing should be avoided. Routing should avoid sharp bends or kinks. A radius of 9 in. (22.9 cm) is considered good practice and helps reduce wear, impact fusion within the hose, and pressure drop.

Frequent visual inspections of the hose should be made to detect internal wear, external wear, and soft spots.

There are a variety of powder hoses and sizes on the market. The most widely used sizes are 1/2 in. (1.3 cm) and 5/8 in. (1.6 cm) for standard powder; 3/8 in. (1 cm) for porcelain-enamel powder, and 3/4 in. (1.9 cm) for collection-hopper transfer hose.



Powder Booths

There are two main functions of powder booths: to contain oversprayed material and to recycle powder material for reuse (see Figure 11-1). Efficient recovery of oversprayed material is an important aspect of an electrostatic powder-spray system (see Figure 11-2). Not all booths recycle powder, however.

Material recovery is not the only aspect of powder booths that must be considered. Powder booths are vital to contamination-free coatings. These booths require specialized ventilation systems, hardware, and protective coverings for workers. Improperly designed or used powder booths often fail to meet safety standards.

Air is pulsed from inside a filter in powder booths so that the powder is forced off the filter or cartridge and drops to a collection device. Generally, the powder drops onto a fluidized plate, runs through a sieve, and is transferred back to the feed hopper. It is important to remember:

- Not all equipment recycles oversprayed powder; some companies spray to waste.
- There are a variety of styles of materials that make up a powder booth. They can be open-faced or conveyORIZED, with the latter offering continual paint coating and powder recycling.

Open-faced booths, also called batch booths, limit production and powder recycling. Coating in an open-faced booth normally is a manual-painting operation. The booths work well with small

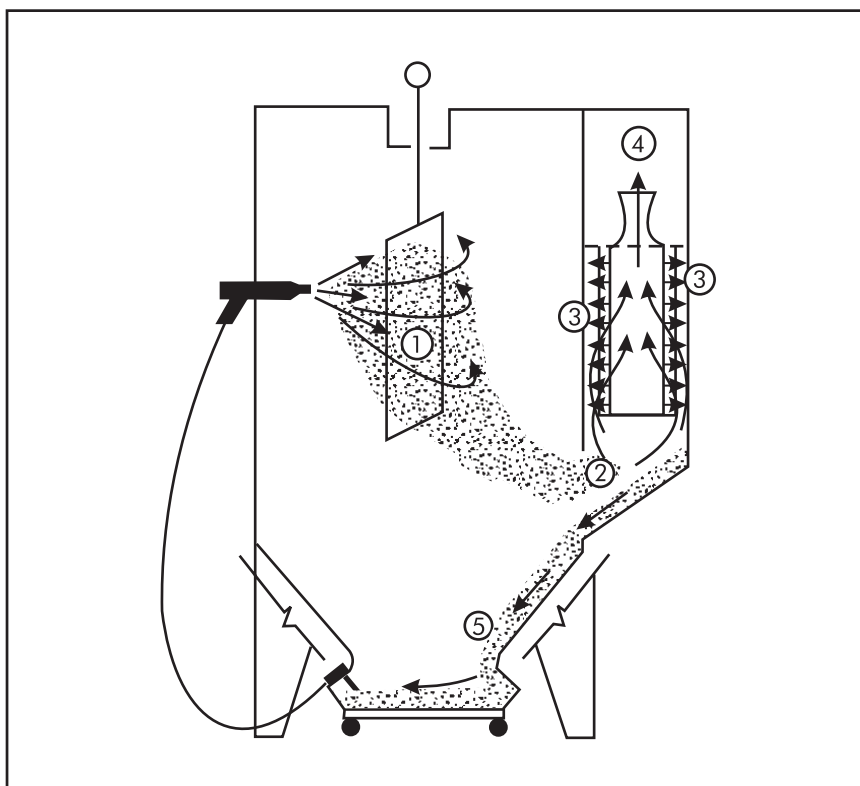


Figure 11-1. Recovery system. (Courtesy INSA Command-Aire Systems)

batches or in shops where money or space is limited. In an open-faced booth, the following occurs:

1. The electrostatic gun sprays the powder, which flows freely around the part, uniformly coating its surface.
2. Powder-laden air enters the cartridge-module unit where powder collects on the filter cartridge.
3. Jets of high-pressure air automatically and thoroughly clean the cartridge filter.
4. Clean air is returned to the plant area.
5. Powder is removed from the filter and falls into a fluidized-hopper bed for reapplication by the electrostatic guns.

Air movement provides the primary tool in most methods of collecting excess powder. In designing and choosing an airflow

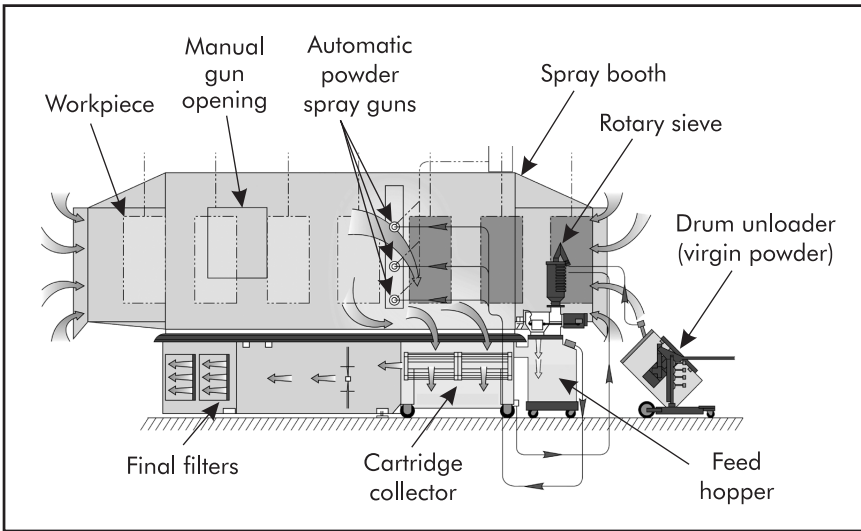


Figure 11-2. Typical function of an electrostatic powder-spray system.

system, a company must consider worker comfort and safety, as well as operational efficiency. Figures 11-3 and Figure 11-4 are examples of spray booths.

Collection systems must address the following requirements:

- worker comfort and convenience during system operation;
- ease and quickness of installation;
- safety and insurance agency approval, particularly for fire and explosion prevention;
- minimization of operational-noise levels for worker protection;
- control of air movement in spray zones to maintain efficient application transfer;
- ease and speed of color changes;
- efficient separation of powder from air volumes; and
- containment of overspray to limit worker exposure and minimize housekeeping efforts.

DESIGN CRITERIA

Paint booths are available in a variety of designs. They can use different methods of transporting items for coating, various ways



Figure 11-3. Conveyorized booth with manual/automatic guns. (Courtesy Nordson Corp.)

to collect extra powder, be built of differing materials, and provide several ventilating options.

Booth design must take into account the use of multiple colors, humidity levels, hardware for transporting items to be painted, and worker safety. The cartridges used to collect unused power can vary, as can cleaning options and ventilating systems. Proper worker clothing, in addition to offering safety, is essential to producing uncontaminated coatings.

Most powder-coating booths are specially designed for individual installations and must accommodate:

- the size of the parts to be coated in the booth, and
- booth-airflow requirements.

A proper system for recovering powder from an electrostatic spray booth entails numerous considerations, but booth design is the primary one. The number and size of openings in the booth determines the cubic-feet-per-minute capabilities required of the



Figure 11-4. Booth for manual-spray operation. (Courtesy Nordson Corp.)

fan that draws air into the booth to contain powder that otherwise would migrate out. Designers should keep the following in mind:

- The booth should be large enough to allow clearance for the largest parts. It also should allow ample access to parts for automatic or manual-spray operations, and permit proper face velocity of air at the openings.
- Work openings should be properly positioned in relationship to parts being sprayed to ensure maximum-coating efficiency.
- Spacing of spray guns within the spray booth must permit changes for coating many parts, as well as racking arrangements for various parts.
- The length and height of the booth must be ample enough to conduct spray operations within the booth enclosure. Current line speeds, possible changes in line speeds, load density

of parts, and hanger spacing are important factors to determining booth size.

- Airflow through the booth must properly contain sprayed powder within the spray enclosure. This airflow must also safely and efficiently transport oversprayed powder from the booth to the collection hopper.

Batch Booths

Airflow in a batch booth is either backdraft or downdraft, and is designed to coat individual parts. Figure 11-5 shows a typical batch booth. Usually parts are hung on a T bar or a swivel-type table or are brought into the booth on a rack.

Some powder batch booths are small, allowing the operator to apply powder to the part from outside of the booth. Others allow the operator to do his or her job from the inside.

Most batch booths are spray-to-waste booths; that is, the collector housing does not recover oversprayed powder. Some batch

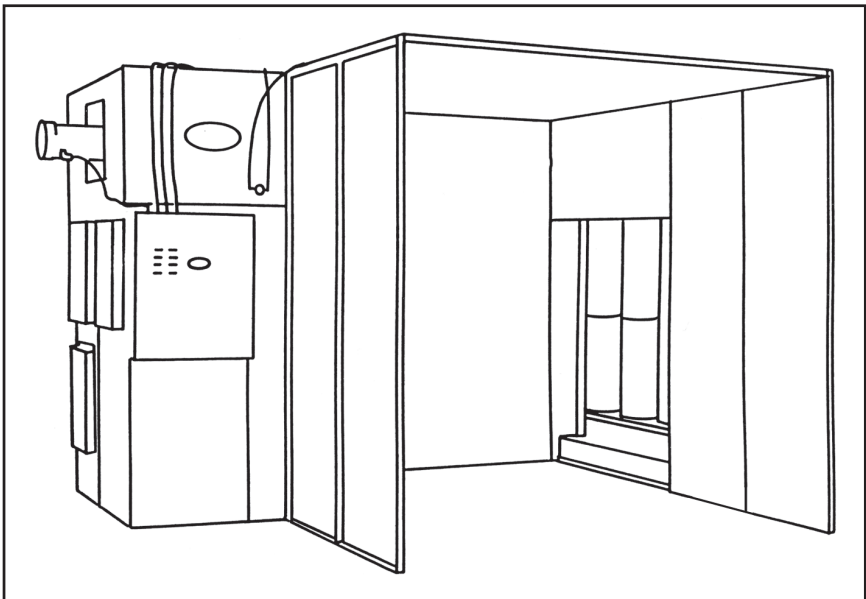


Figure 11-5. Typical batch booth.



booths can be set up to recover powder, but usually the booth simply is exchanged for a conveyor system if recovery is desired.

Conveyorized Booths

Many companies manufacture conveyor spray booths designed for efficient, continuous spray powder application. In these booths, the conveyor runs over the top and outside of the booth, which has a slot that runs the length of its roof panel. Openings for the product are at each end of the booth (see Figure 11-6). These are the premiere booths for high production quantities. The products coated can be small or large. There are usually slots and doorways along each side of the booth to allow for painting manually or with automatic guns. Automatic-spray equipment should have UV-spark/flame-detection systems at each end of the booth, and ventilation to maintain a powder-concentration level below 50% of the lower explosion limit (LEL).

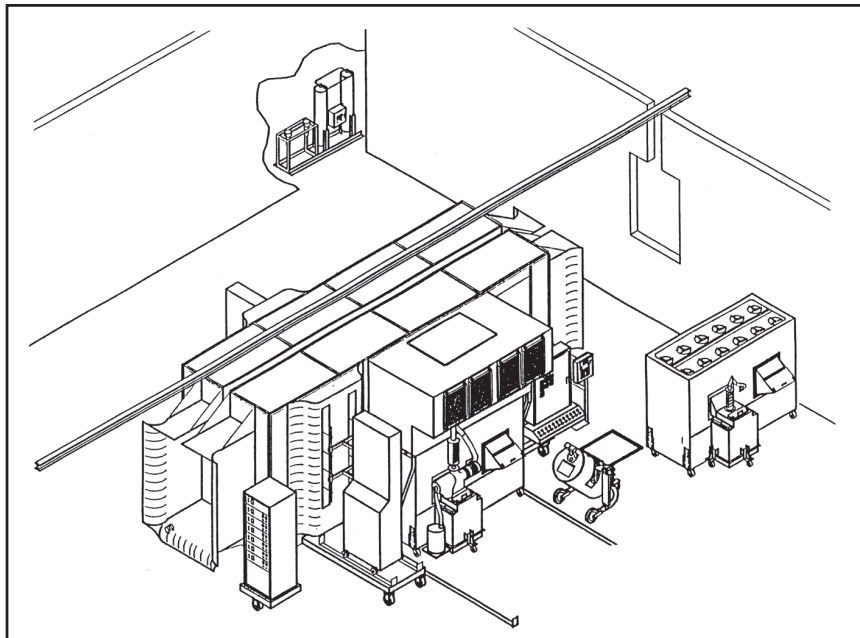


Figure 11-6. Conveyorized booth.

Conveyorized booths offer a variety of means for ventilation and excess-powder recovery. Booth ventilation options include gravity-cyclone, side-draft, belt, chain-on-edge, and cyclone systems. Several different cartridges are used for collecting excess powder.

Gravity-cyclone Booth

In a gravity-cyclone system, gravity causes about 50% of the overspray to fall into the feed hopper. The balance is collected through an extraction duct that goes to the reclaim system. In this booth, the reclaim system is an almost self-cleaning cyclone separator with recovery efficiencies of 90–95%. A small fraction of powder remains in the air stream from the cyclone. This powder is separated in the final filter before air returns to the room.

In gravity-assisted recovery booths, gravity returns a portion of the overspray directly to the feed hopper without entering the reclaim system. This minimizes the reclaim powder generated within the system.

Side-draft Booth

Side-draft booths draw in air from the side of the booth. Many times the movement of the air is from the front of the booth to the back. These booths work efficiently and are usually used in conjunction with rollaway collection modules. They allow fast color changes and use space efficiently. Figure 11-7 shows a side-draft booth.

Cartridge filters are used in the side-draft booth. The rollaway modules are easy to use and made for easy cleaning. A sensor in the external feed hopper automatically controls the flow of recovered overspray from the collector back to the feed hopper on demand. This improves fluidization of powder material and ensures optimum coating performance.

Belt Booth

In a belt booth, a moving belt in the bottom of the booth travels in a horizontal loop along the booth floor. The airflow created by

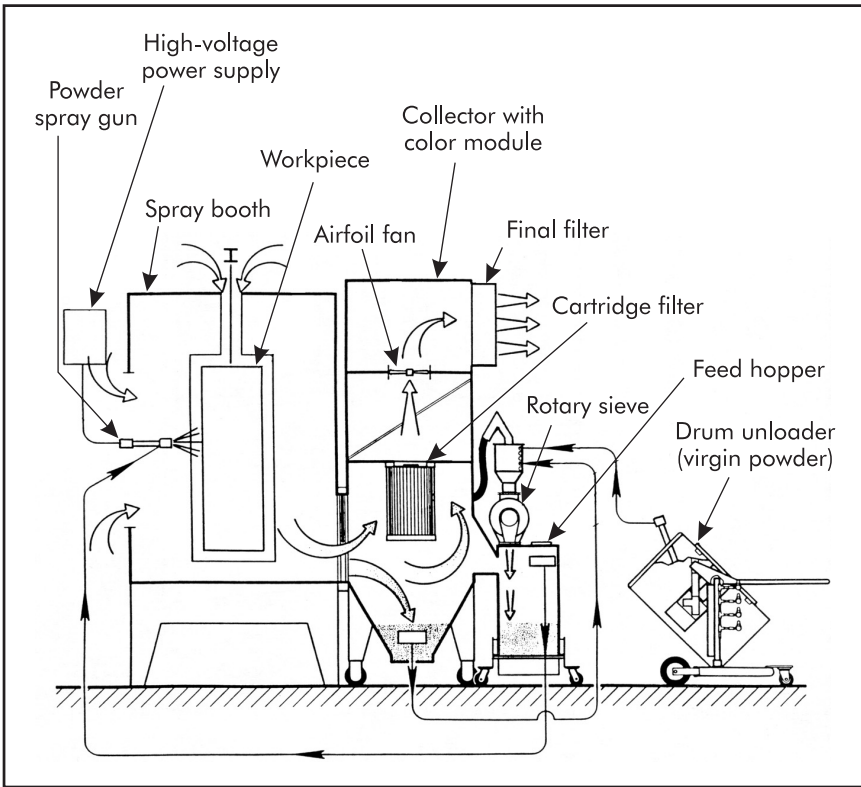


Figure 11-7. Side-draft booth.

the booth exhaust system draws the oversprayed powder to the belt surface. A pickup head—located at the end of the booth—vacuums powder particles trapped on the belt surface. Once removed from the belt, powder is sent through the reclaim system to be separated from the vacuum airflow and prepared for reuse.

Chain-on-edge Booth

In a chain-on-edge booth, cartridge filtration recovers the powder. This type of booth coats products that are passed through on a spindle conveyor. The conveyor for this booth is floor-mounted and uses a pressurized shroud to keep powder off the conveyor as the parts are coated.

Cyclone Systems

In a cyclone system, the powder-laden air stream enters the separator and follows the curvature of the separator's walls to form a spiral, rotating pattern. The airflow generated by the recovery fan draws the oversprayed powder into the booth's recovery canister. Airflow, produced by a blower, creates a vacuum in the booth through a ductwork system connected to a cyclone, which is used as the primary means of powder separation and recovery. Powder enters the cyclone at a velocity of 60 ft/sec (18.3 m/sec). The cylindrical cyclone swirls the mixture so powder particles drop into the reclaim canister at the bottom. Finer powder particles bypass the reclaim canister as a collector pulls them into a scrap barrel. Thus, the system is self-cleaning.

Powder Collection

Powder booths require powder-collection systems with sufficient velocities of air coming in the booth openings to contain oversprayed powder. Figure 11-8 shows a typical cartridge canister.

Cartridge collectors normally are used for their high efficiencies and relatively low cost. The cartridge filters are usually constructed of pleated, unwoven materials like cellulose and paper. Some companies now use an aluminized pleating designed to pulse most of the powder clear of the pleating. This saves money because this style of cartridge does not retain powder within its pleats. Standard cartridges can retain up to 20 lb (9 kg) of powder.

Paper cartridges need to be seasoned to extend their life. To season a cartridge, virgin powder is sprayed onto the filter media, ensuring that larger powder particles are next to the filter, thus letting the fan draw air through the filter. Without seasoning, the cartridge would build up fine powder against the surface and the draw would be reduced significantly. Some polyester cartridges do not need to be seasoned. Buyers should check with their equipment supplier.

In collection systems, manometer-gage probes are placed before and after the cartridge, allowing the system to determine when filters are blinded or plugged with fine powder. Sometimes this excess powder can be cleaned off by increasing the pulsing mechanism or by having a stronger pulse sent to the cartridge.

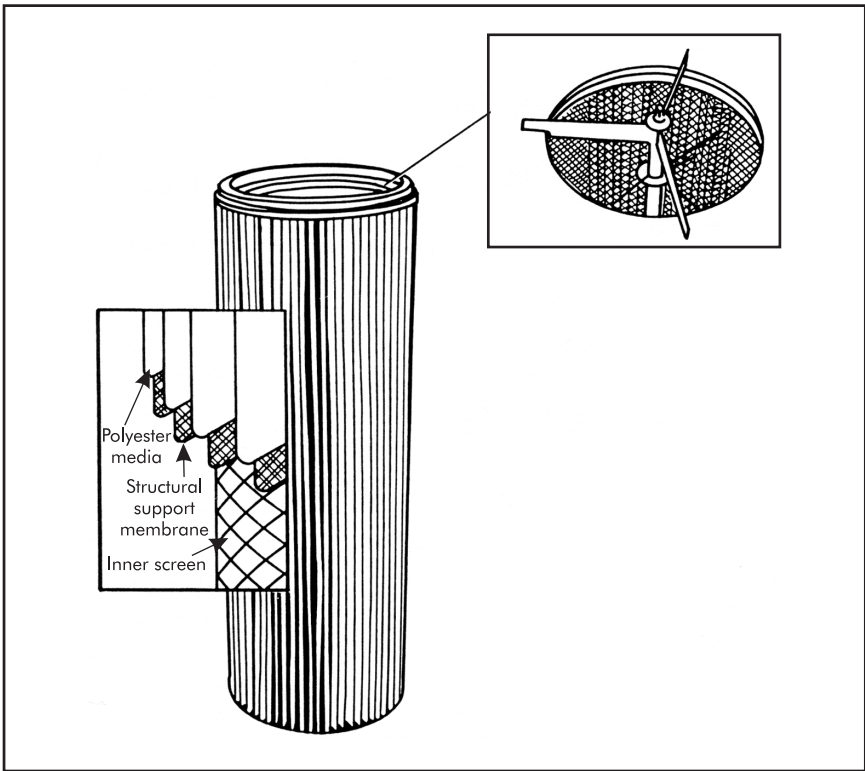


Figure 11-8. Typical cartridge canister.

Excessive moisture in the air supply or high air humidity in the room can result in cartridge clogging that damages the filters so much that they are beyond cleaning. Moisture will also clog exhaust final filters (secondary filters). Clogging results in higher rejection rates and increased powder costs.

When installing new cartridges, users must take special care not to hit the pleating or let anything contact the pleats. If pleats are damaged, the air drawn through the cartridge is changed. Since there would be no reduction or resistance of airflow in the area of the damaged pleat, increased air velocity can occur. This increase in air velocity can change the powder cloud and flow inside the booth. It also allows waste powder to enter the filter instead of being trapped on the outside where it can be further processed. Unfiltered air will draw powder into and through the canister.

Determining Booth Fan Size

A fan creates airflow through the powder booth. The face velocity of air coming across the opening of the booth is critically important to maintaining proper powder collection within the booth.

The face velocity required to contain powder in the booth should be no less than 100 ft/min (30.5 m/min) and, in any opening, the average velocity should be at this level or higher. This can be measured with a face velocity meter (see Figure 11-9).

In the fan and cartridge area, water manometer gages measure when the filters become blinded with fine powder and fail to draw adequately. At this point, new filters should be installed or existing filters cleaned.

The equation to determine the airflow required is:

$$V_A = (H \times W) \times F_V \quad (11-1)$$

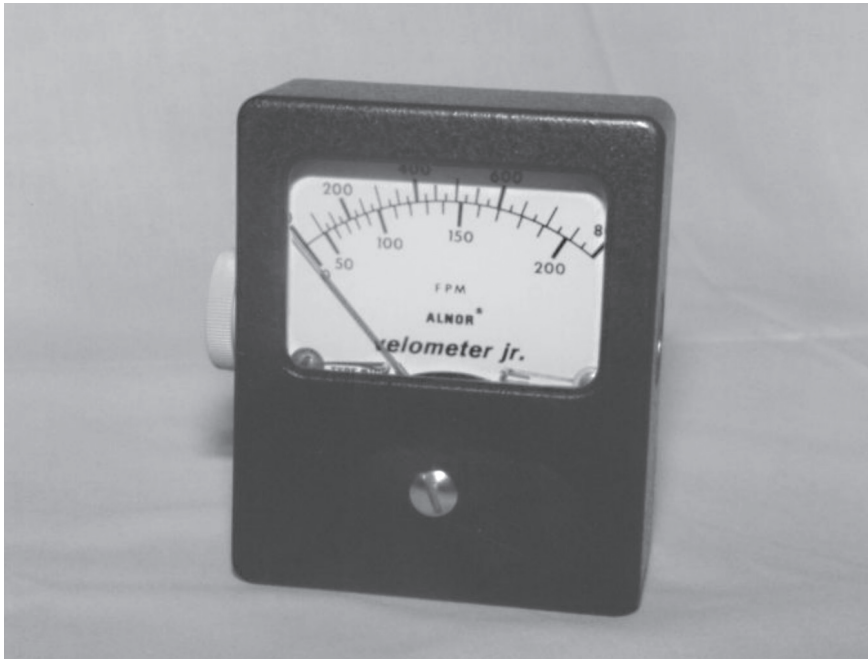


Figure 11-9. Face velocity meter.

where:

V_A = airflow volume, ft³/min (m³/min)

H = height of booth opening, ft (m)

W = width of booth opening, ft (m)

F_V = face velocity, ft/min (m/min)

To calculate:

- Multiply each booth opening ($H \times W$) to establish the area of the openings. Remember to include every opening including the conveyor slot, automatic gun slot, access doors, and part entrances and exits.
- Add the total area of the openings and multiply this by the face velocity needed, starting with at least 120 ft/min (36.6 m/min).

This provides the ft³/min (m³/min) the fan needs to provide. For example: Total opening area = 100 ft² (9.3 m²) $\times$ 120 ft/min (36.6 m/min) = 12,000 ft³/min (339.8 m³/min) required from the fan to create sufficient average face velocity of 120 ft/min (36.6 m/min).

Always start with more face velocity built into the system because, over time, filters become blinded and face velocity declines.

Never go over 150 ft/min (45.7 m/min) face velocity or the powder probably will be drawn into the collection hopper before it is applied to a part.

Air velocity is the speed of the air required by regulation or code. A spray booth requires the minimum air draft, in lineal measurement, needed to carry excess spray through the booth, past the operator or automatic equipment, and deposit it in the collection hopper.

A handheld velometer that measures air speed in feet per minute or meters per second will indicate how fast the air is flowing (see Figure 11-9). For example, if required minimum airflow volume through the booth is 12,000 ft³/min (339.8 m³/min) and the booth has 100 ft² (9.29 m²) of opening area, the velometer would read 120 ft/min (36.6 m/min) when 12,000 ft³/min (339.8 m³/min) is achieved or:

$$[(120 \text{ ft/min (36.576 m/min)} \times 100 \text{ ft}^2 (9.29 \text{ m}^2)) = 12,000 \text{ ft}^3/\text{min (339.8 m}^3/\text{min)}]$$

In this example, when airflow falls below 100 ft/min (30.5 m/min), it may be time to change the primary cartridge filters because they are clogged (termed *blinding of a filter*).

Points to remember about controlling air velocity include:

- The static-pressure-drop readings at each stage indicate if any filters have reached their recommended and/or final pressure drop (whichever is lower) and should be changed. Usually, this is determined by a manometer gage.
- Clean filters should not be checker-boarded with dirty filters because this could create non-uniform airflow conditions in the system or powder booth. Other conditions, such as a supply fan not running, can result in reduced airflow in the booth. System components should be checked to find the source of the problem.
- Air volume is a key factor to ensuring an adequate draft to remove excess powder. It reflects the amount of air needed to move through the booth and into the exhaust chamber. Air volume is determined by:

$$(V_A = A \times C) \quad (11-2)$$

where:

V_A = air volume, ft³/min (m²/min)

A = area, ft² (m²)

C = velocity, ft (m)

Color Changes

Color changes involve a trade-off among time, cost, and floor space. They are required in most applications and there are several ways to make them. Most single-booth systems are spray to waste—each powder color is sprayed and then thrown away. Many single-booth designs include color modules made to attach to the booth and later are removed. Each module carries a different color.

If there is no further use for a particular color, the operator simply takes the cartridge filters that hold the color pigment out of the module. He or she cleans the residual powder from the module

and installs the new filter(s). In spraying to waste, the decision on amount and cost of powder to be thrown away should be compared to the cost in time, equipment, and labor involved in recovering and reusing it. Long runs and large volumes may prove cost justifiable, but smaller and shorter runs may be uneconomical. Spray to waste may make the most sense in powder coating operations like job shops where there is a tendency to powder coat varieties of parts.

Factors to be considered in determining the feasibility of color changes include:

- customer requirements;
- powder costs;
- number of colors needing change; and
- frequency of color changes.

In addition, consider the amount of powder being sprayed and what would need to be claimed. For example, if a coater is using the same color again, at a different time, and a great amount of material is being sprayed, there may be a considerable need for reclaiming the overspray. On the other hand, if only a few pounds of powder are being sprayed and the color will not be used again, the coater is probably spraying to waste.

For a single-color booth with an extra module, the necessary equipment includes:

- extra color module or modules;
- additional hoppers, including pumps for gun(s); and
- color-dedicated hoses.

To make a color change, the operator should:

- Use compressed air to blow out the guns into the collection hopper.
- Blow powder out of the pump assembly.
- Squeegee down excess powder on any surface within the spray booth. This powder should be put into the collection hopper for reuse.
- Blow down residual powder from the walls into the collection hopper (sometimes vacuuming works well).

- Use a clean, damp cloth to wipe down the interior of the spray booth.
- If using a color module, remove it from the booth and clean the edge where the module was attached.
- Install the next module.

The time required to clean and change colors in any given situation depends on the color, properties of the powder, booth size, material making up the booth, and the employees performing the task. It is best to have at least two people make a changeover. Each person should have designated tasks to perform so there is no repetitive work done.

It is important to remember that powder paint does not blend as wet paint does. For example, if a little wet white paint mixes with a large amount of wet black paint, little difference is perceived. With dry powder coat, a pinch of white powder will contaminate an entire paint booth and collection system. White powder specks will eventually appear on every part.

It is critical that crevices and cracks are cleaned of powder when making a color change.

One way to make quick color changes is to employ multiple paint booths. One booth is rolled off-line and another is rolled on-line, resulting in little production downtime. When the booth is off-line, employees can clean it more effectively and less hurriedly. However, the cost of multiple booths must be studied to determine the feasibility of this system. For many companies, it is imperative that production not be stopped. Multiple booths can be set up with every booth on-line together in-line, but this results in a high potential for powder contamination. If more than one booth is simultaneously in operation, there are dedicated conveyor systems for each paint booth. (Power-and-free conveyors work well with multiple booths.) Typically, in multiple-booth systems, one powder booth is dedicated to the more frequently used powder and the other is used as a spray-to-waste booth.

Many people in the finishing field continue to address the issue of making quick color changes. No matter the design or system installed, a company must make sure proper cleaning and changeovers occur. Each paint operation forces a decision regarding the number of booths to install, the powder cost, the volumes needed, and number of needed color changes.

PAINT BOOTH MATERIALS

Powder booths are made from a variety of materials, but most are steel, polypropylene, or stainless steel. Painted steel booths are most common because painted steel is more economical than the other materials. In addition:

- It is easily constructed and installed.
- It has durability and strength.
- It can be painted when needed.

Stainless steel has the advantage of increased strength and rigidity. Stainless steel provides:

- a smoother finish for easier/quicker cleaning; and
- enhanced light reflection.

Polypropylene (plastic composite) costs approximately the same amount as stainless steel. Its benefits include:

- a smooth finish makes for easier, quicker cleaning;
- light transfers through it for better vision; and
- powder is less attracted to it due to its nonconductive nature.

FIRE PROTECTION

Recovery systems must be designed, installed, and operated properly because spray-booth efficiency is a must. A major hazard can occur with any powder system—an explosion within the confines of the powder booth or collection system. A fire or explosion may occur as a result of a spark being generated where the concentration of powder particles in the air is above the LEL determined by the powder manufacturer.

Combustion occurs in the presence of oxygen, fuel, and ignition sources. In the case of a powder booth, the powder (source), the air (compressed), and ignition sources are present. Therefore, booth maintenance and housekeeping are important.

NFPA Code 33 specifies that all automatic or fixed powder-coatings systems must be equipped with a flame- or spark-detection device and components must automatically shut down should there be detection.

Ignition sources can be cigarettes, open flames, electrical equipment, and parts that have not been properly grounded. Powder coating is fairly difficult to ignite, but epoxy powder, once ignited, will create its own oxygen source and burn rapidly. Parts racks coated with epoxy powder and then sent to a burn-off oven present little fire hazard. Most epoxy racks are weighed before they enter the burn-off oven so that only a predetermined total weight of powder is roasted. If this precaution is not taken, powder could burn out of control.

An important step to prevent powder ignition is to be certain that the ground points of any racks or hangers are at or below at least 1 mega-ohm. This ensures that arcing will not occur and there will be the highest transfer efficiency.

Spark detectors in the booth react to arcs, which are a source of ultraviolet (UV) light. When the UV is dangerously high, the system immediately shuts down electric power, powder flow, and air to the booth—reducing explosion risk and any fire that may have started.

The UV-detection system is the first one to be used in powder booths. It triggers rapidly, detecting a small amount of UV light, usually coming from the ground area on the racks. The first UV detectors were hard to control, booths were continually being shut down. Detector companies redesigned their equipment for on-site modification. This helped, but a newer UV/IR system was developed to replace the old.

If a fire develops in the powder booth, it rapidly moves to the collection hopper and ductwork that runs to a cyclone. Cyclones are required to include separate damper areas that shut down and close ductwork leading to them if they detect a flame. If fire reaches the cyclone during operation, an explosion could occur. Proper venting of cyclones is a must in this type of emergency.

HUMIDITY

Humidity is a critical factor in controlling contamination and film thickness within a paint system. Floating fibers and dust need to be controlled and humidification is the best means to accomplish this. Attaching moisture to powder particles makes them heavy and causes them to drop out of the air. It has been observed

that when it rains, dirt is washed out of the atmosphere. Less foreign particles in the air mean fewer particles will float to paint surfaces prior to curing of the paint. Less contamination also gets into the feed and collection systems.

Controlling humidity can be accomplished by several methods, including:

- spray coils;
- spray nozzles;
- rigid-media humidification;
- steam injection;
- atomizing nozzles at the burner; and
- ultrasonic humidification.

Each of these methods could, however, contribute to particulate contamination, something to be considered when choosing a method to control humidity.

Humidity can reduce static electricity, but dry air increases it—the dryer the air, the higher the static charge. Static electricity can cause a part to act as a magnet, attracting and holding contamination. This is similar to electrostatic painting where a charge is used to apply powder to a part for better transfer efficiency. But a contaminant behaves like powder when charged; it attaches to the part to be painted, and once attached is difficult to remove. Increasing humidity in air reduces static charge and thus reduces particulate contamination. In a powder paint area, this is even more critical because negative airflow to the booth pulls in outside air, thereby producing a cloud that hangs in the application area.

Increased humidity (about 50–60% rigid-media humidification) helps reduce the static charge of contaminants and enhances the powder's electrostatic charge for better transfer efficiency. Low humidity decreases the powder's attraction, yielding low film thickness and requiring a voltage increase to maintain the appropriate coating.

AIRFLOW FACTORS

The spray zone—the area where powder is being applied—can be disrupted in many ways. Disruptive sources include air make-

up units, opened doors, and outside weather conditions. The parts in a powder booth require a consistent air velocity enveloping them—disturbance of the air envelope results in contamination. Air movement within powder booths is much more particular than in liquid booths due to the make up of powder particulate. Even a small degree of outside air-source disruption—and sometimes inside disruption—disturbs proper airflow.

Planning and placement of equipment is a top priority in controlling contamination. A proper facility is one of the most important factors to consider when planning a powder-coating system. Being able to design the facility from the ground up is the ideal situation, but many systems must be installed within available plant space.

Factors inside and outside a facility make the general location of the operation important. Even a properly designed powder-coating booth can have failures that result in accidental migration of powder to the surroundings. Thus, consideration should be given to ambient in-plant operations that could be affected by such failures.

Migrating powder from even a well-designed system can occasionally become troublesome. If stray air currents pick up powder, a small amount of the powder may cover a large area. This powder accumulates over time on ledges and structural members. Enclosures with smooth walls and no catchall framework are desirable for easier maintenance.

When designing an equipment layout plan for a powder operation, each element's location should be carefully analyzed. For example:

- Overhead framing should be avoided at this early stage.
- Exhaust from booths and ovens should be direct.
- Conveyors can be more easily mounted when they are positioned near adequate structural members in the building.

The location of doors and windows is of great importance. Spray booths provide uniform and consistent airflow to transport the powder. A door or window opened next to or in the vicinity of a booth may disturb the booth airflow and cause difficulties. Powders may leave the booth, distorting the spray pattern, and drawing outside dust and contamination onto the coating.

A controlled atmosphere for the coating booth and powder storage room is desirable. This is particularly necessary to meet the challenges of temperature and humidity. Exposed powder readily picks up moisture and is somewhat temperature sensitive. The painting operation is improved if conditions can be standardized.

HOOKS AND RACKS

Part hooks and racks play an enormous roll in powder-paint applications. Hangers assist in line density and are the ground for parts. Good hangers also offer higher transfer efficiencies and better coverage, with less overspray and fewer rejects.

Efficient powder coating requires 1 mega-ohm or less of resistance between parts and racks or the ground. If parts are incorrectly grounded, proper powder application will not occur. Good grounding is mandatory for the electrostatics of the application gun to set up a corona field and properly charge the powder. If powder is applied to parts without the ground, the powder will pick up other ions that are in the region as it seeks a grounded surface. Many times, poorly designed and maintained hangers are the cause of poor grounding.

Hangers should be as light as possible and have a small footprint because powder-coated hangers need to be stripped of excess powder; larger, bulkier racks and hangers cost more to strip. Stripping racks and hangers can be costly; the process is needed not only for the ground of parts, but also for safety within the paint operation. Good design and clean hangers allow parts to be uniformly coated with even film distribution. If there is not a positive ground point between the parts and hangers, light parts, uneven coating, and bare spots can occur. Arcing of the hanger can occur because parts store energy from the electrostatic charge and act as capacitors, discharging when near a ground. This can result in a fire or an explosion.

Parts grounding is provided through the parts' contact with the hangers, which are grounded from the conveyor and, in turn, are grounded through other equipment or through earth-rod grounding devices located at the ends of the booths.

Parts should be hung with the highest line density possible to make production more efficient. Whether parts are large or small, adding more of them to a hanger obviously increases production. Since all parts have their own complexities, a variety of hanging methods can be employed to overcome hanging problems within the entire paint system (line loading, washer, paint booth, and ovens). The operator should put as many parts on a hanger or rack as properly can be loaded, cleaned, and painted. If there are enough parts to paint during half of one day, painters should paint them within that half-day, not take all day for the few parts. This is an inefficient habit and sets a bad precedent for future production.

It is important that powder never be allowed to reach the load bars because they are not easily removed for cleaning. Load bars should not enter the booth area and painters should not aim their equipment in a direction that allows powder to land on the load bars. This only results in more maintenance and possible product contamination from powder that lands on top of the booth and later becomes dislodged.

Some parts may need customized hangers. These hangers should permit the best line densities, but ensure proper grounding. There also are a variety of stock racks.

The hook design in Figure 11-10a could present a shielding problem. Shielding occurs when electrostatically charged powder is attracted to the closest ground, which in this case would be the

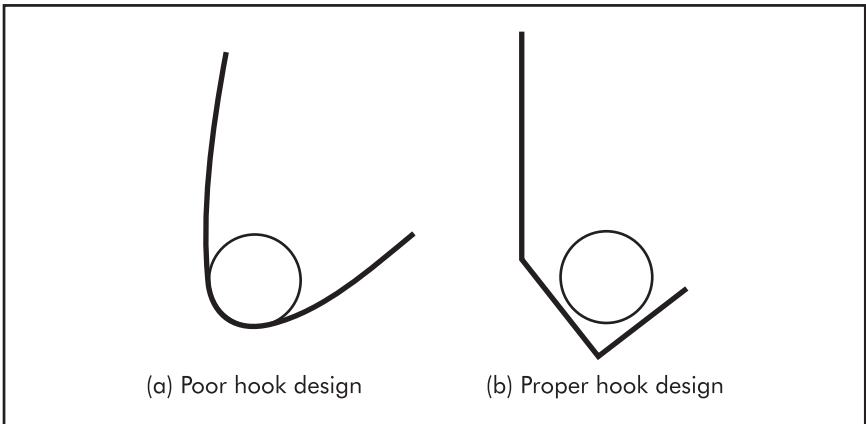


Figure 11-10. Poor and proper hook design.

hanger. The powder does not apply to the parts, but to the hook instead. This robbing usually occurs when the hook is larger in mass than the parts being painted or if the parts are not grounded. The solution is to move the hook away from the part. Hooks need only a single contact point to achieve grounding, but a V-hook design (see Figure 11-10b) goes further to guarantee adequate grounding. These contact points must be free of coating buildup to ensure adequate ground.

Parts should be hung so that they drain properly within the washer system. They should be designed or hung with drain points at the lowest possible level. If parts do not drain properly, cupping action occurs, plus contamination from stage to stage. The solutions left in these cupping areas may not evaporate in the dry-off oven prior to powder application and the parts will become rejects if painted.

Loading the line and spacing parts as close together as possible enhances production quantities, and wastes less powder during application. This waste occurs because powder is not sprayed onto parts, but rather into the booth and collection hopper, assuming automatic guns are used. As powder is constantly recycled in this fashion, powder fines build, making it continually harder to apply efficiently.

Single conveyor-point hangers are preferred when using conveyors with inclines (see Figure 11-11a). They work well unless parts are too large for one hook to hold them. Two points for the

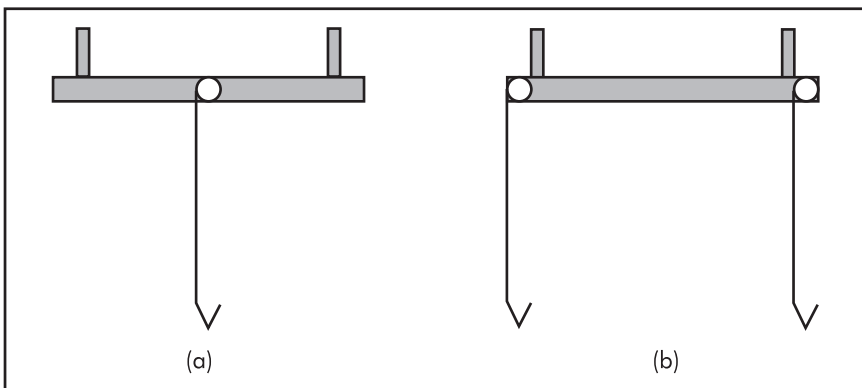


Figure 11-11. Single-hook and multi-point hangers.

rack are needed in this case (see Figure 11-11b). Figure 11-12 shows a conveyor with hanging parts.

CONVEYORS

Unless a company is using batch booths, conveyors are needed to transport the parts through the pretreatment system, the dry-off oven, the powder application area, and the oven. There are many styles of parts conveyors available.

Parts loading should involve as little bending and physical exertion as possible. Heavy lifting should be done with lifting equipment or two people. Pre-racking parts can be an effective alternative to rushing line loaders. Figure 11-13 shows a typical conveyor system.

Line loaders must be certain that parts are not loaded in such a way that they touch one another on inclines or on sprocket-drive corners of the conveyor system. Table 11-1 shows work clearance limits for vertical rises and slopes.

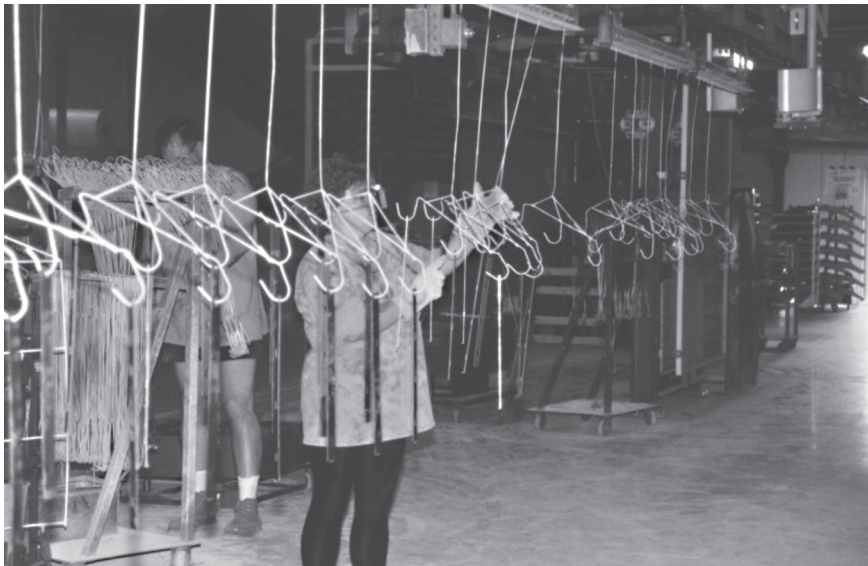


Figure 11-12. Conveyor with hanging parts. (Courtesy Nilfisk-Advance Corp.)

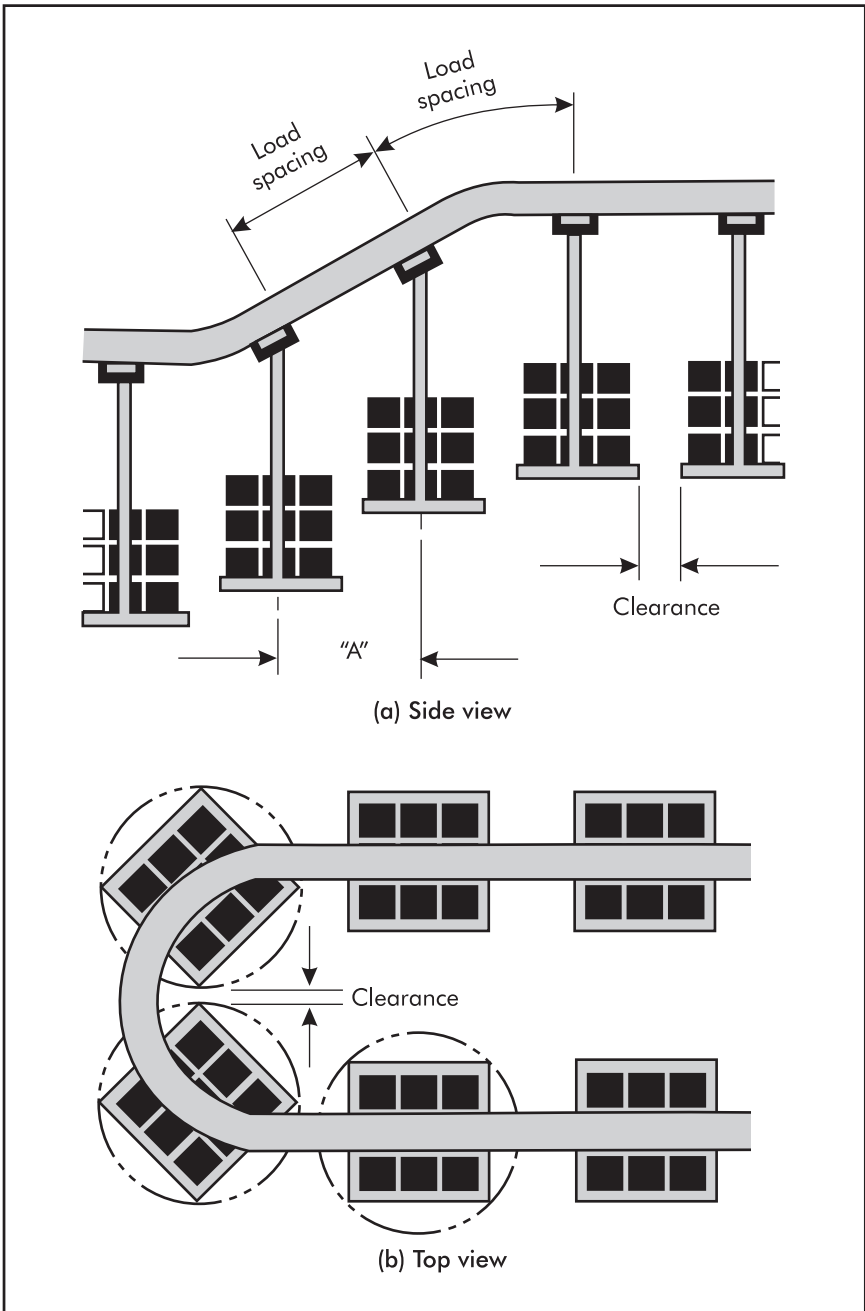


Figure 11-13. Side and top views of a conveyor system.

Table 11-1. Work clearance limits for vertical rises and slopes

Work Center—Level Nominal, ft (m)	Actual, in. (cm)	Work Center on a Slope		
		30°, in. (cm)	45°, in. (cm)	60°, in. (cm)
2 (0.6)	8.125 (20.64)	7.063 (17.94)	5.750 (14.61)	4.063 (10.32)
	16.250 (41.28)	14.125 (35.88)	11.500 (29.21)	8.125 (20.64)
	24.375 (61.91)	21.125 (53.66)	17.250 (43.82)	12.188 (30.96)
	32.500 (82.55)	28.188 (71.60)	23.000 (58.42)	16.250 (41.28)
	40.625 (103.19)	35.188 (89.38)	28.750 (73.03)	20.313 (51.60)
4 (1.2)	48.750 (123.83)	42.250 (107.32)	34.500 (87.63)	24.375 (61.91)
	56.125 (142.56)	49.250 (125.10)	40.250 (102.24)	28.438 (72.23)
	65.000 (165.10)	56.313 (143.04)	46.000 (116.84)	32.500 (82.55)
	73.125 (185.74)	63.375 (160.97)	51.750 (131.45)	39.563 (100.49)
	81.250 (206.38)	70.375 (178.75)	57.500 (146.05)	40.625 (103.19)
8 (2.4)	89.375 (227.01)	77.438 (196.69)	63.250 (160.66)	44.688 (113.51)
	97.500 (247.65)	84.438 (214.47)	69.000 (175.26)	48.750 (123.83)
	105.625 (268.29)	91.500 (232.41)	74.750 (189.87)	52.813 (134.15)
	113.750 (288.93)	98.563 (250.35)	80.438 (204.31)	56.875 (144.46)
	121.375 (308.29)	105.563 (268.13)	86.188 (218.92)	60.938 (154.78)

Applications and Operating Conditions

The correct selection and setup of powder feeders, pumps, hoses, and spray guns strongly affects the final finish. Powder can affect the result of the process as well. The powder particles' size distribution is critical to successful powder coating.

Specific powder types are ground to specific micron sizes. When powder manufacturing companies grind powder, they try to get the most powder possible (the highest percentage) within 0.001–0.002 in. (25–50 μm) in size. Most powder should be in this micron range, as powder particles within this size possess optimum charging efficiency.

Once powder is ground, a laser inspects it and a statistical report is issued. This report indicates the majority size of the particles. The grinding process used in powder production is unable to make every particle exactly the same size. Some particles are coarse and some are fine. Neither extreme is able to take on good charging characteristics.

PARTICLE-SIZE DISTRIBUTION

A histogram of particle-size distribution should show a narrow peaked shape. Broad, flat distributions indicate large percentages

of both coarse and fine particles to be present. These particles possess a number of undesirable properties including:

- poor fluidization,
- lowered transfer efficiencies, and
- rapid buildup of fines.

It is important that not only the mean size, but also the distribution curve's shape be adjusted to meet job requirements. For example, when smoother, high-gloss finishes are desired, finer-grind powders often are required.

While the powder process is dependent on electrostatics (without charged powder there is no process), the powder-spray process is only about 50% electrostatics. The other half depends on the amount of airflow shaping the patterns and transporting charged powder to the parts.

Wrap is an electrostatic phenomenon. Without charge, there is no evidence of wrap. But it is not electrostatics transporting powder to the back edge flat panel or the backside of a round tube; aerodynamic turbulence provides the transportation.

Deflectors

Many deflectors can help provide pattern control for finishing any part configuration. The way the powder is distributed from the spray gun and directed to the part can be regulated by pattern control.

Deflectors make a cloud-like formation. Conical deflectors leave circular clouds and effectively penetrate recessed areas. They can make a cloud pattern from 1–18 in. (2.5–45.7 cm), depending on the gun's settings and the distance to the part.

Flat-spray deflectors are effective for flat panels or large parts. Common fan patterns range from 6–14 in. (15.2–35.6 cm).

Penetration

Penetration is most important when applying powder coating on complex parts. Boxes, extrusions, or parts with many corners

exhibit Faraday caging problems. Crosscut flat sprays or smaller conical deflectors overcome these conditions. Selecting the right deflector for the job helps ensure uniform coverage on any part. Pattern control is best accomplished with conical pattern deflectors because the velocities can be controlled more accurately. Table 12-1 shows some deflector applications with the appropriate nozzle type.

OPERATING CONDITIONS

For electrostatic powder-spray guns to function properly (and safely), the following conditions should be maintained:

- Metallic, fixed-powder-spray guns must be adequately grounded at their points of support to reduce the possibility of static-charge buildup on the gun and the discharge of this static charge to a part or component in the spray area.
- Manual powder-spray gun operators must be adequately grounded (usually through the handle of the spray gun) to prevent static-charge buildup on the operator's body during spray operations.
- Powder-spray gun parts that contact moving powder must be inspected and cleaned on a regular basis. Parts that contact moving powder are prone to wear (if the powder material is abrasive) at high velocity and they impact fusion. Worn parts result in poor control of powder flow, accentuated impact fusion, and a need for more frequent cleaning. If a part is worn, it should be replaced.
- Electrostatic powder-spray guns (manual and automatic) should be checked periodically to determine the level of electrostatic charge being imparted to the powder material. The lack of, or decrease in, expected electrostatic charge indicates a problem in the electrostatic system. These problems should be corrected as soon as possible. To reduce the possibility of electrical shock, troubleshooting guides should be consulted when inspecting or repairing any component within the electrostatic system.
- With fixed or automatic powder-spray guns, interlocks should be used to rapidly de-energize the high-voltage elements

Table 12-1. Some deflector applications and nozzle types

Application	Nozzle Type
Part shape:	
Flat panels	Flat spray (automatic guns) Small deflector (manual guns)
Round stock	Conical
Recesses	Small deflector
Product type:	
Refrigerators and freezers	Flat
Washers and dryers	Flat
Furnace, home	Flat
Lighting fixtures	Flat
Kitchen stoves and ranges	Flat
Water heaters	Flat
Wrought iron furniture	Conical
Cast iron furniture	Conical
Tables, steel	Conical and flat
Chairs, steel	Conical and flat
Metal cabinets	Flat and pinpoint
Desks	Flat and pinpoint
Partitioning	Flat
Shelving	Flat
Stamped steel parts	Conical
Cast iron parts	Conical
Lawn mowers	Flat
Snow blowers	Conical
Wheelbarrows	Flat
Metal toys	Conical or flat

involved with electrostatic spray under any of these conditions: stoppage of ventilating fans or failure of ventilating equipment; stoppage of conveyor carrying goods through the high-voltage field of electrostatic spray; or other conditions as prescribed by regulatory agencies.

Gun Movers and Reciprocators

Many powder-coating systems rely on reciprocating equipment to paint products. Automatic guns are the best choice for uniformity and consistency in the finishing application. Automatic guns provide film thickness and even particle distribution. They generally require more oversprayed powder to be collected and recycled for reuse.

Usually, multiple guns are arranged on both sides of a booth. These automatic guns can be fixed or robotic. Fixed guns can be arranged vertically and/or horizontally. A stand for holding these guns is mobile and can be moved to locate the position of the automatic gun in respect to the part needing paint. In a fixed system, the guns themselves do not move and, therefore, fixed systems require more guns to cover the surface than do reciprocators.

Oscillators/reciprocator-type guns can be mounted vertically or horizontally and have an advantage as the guns move up and down. This movement provides a more uniform-coverage pattern and necessitates fewer guns for the surface area. Usually oscillators are flywheel-driven and reciprocators are electric-cam-, pneumatic-, or chain-driven. The travel and speed usually can be controlled and tailored to each part being coated.

When a powder booth includes a controller and automatic equipment to apply powder, the booth must have a flame/spark detection system at the booth's entrance and exit. This detection system must be able to detect a pre-specified amount of energy and shut down electricity and air to the booth. This insures that powder feeding to the gun will cease in the event of a fire.

Gun Triggering

Triggering represents significant cost savings in the powder-coating system. It saves powder from becoming powder fines. (*Powder fines* describe oversprayed powder. When powder is applied to a properly grounded substrate, a certain micron portion of the powder is attracted to the substrate; the rest bypasses the part and is pulled to the filters. Powder fines can be both larger and smaller in micron size than what is considered to be to the

optimal size. Again, most optimally sized particles remain on the substrate.)

Gun-triggering systems work with reciprocating equipment. A gun-triggering system lets automatic guns shut down after a pre-specified time and triggers them on to paint when needed. Thus, powder is not wasted if a part is not present to be painted.

Delays are built into gun-triggering systems as, like almost all powder systems, a few seconds elapse while powder is pumped from the feed hopper to the gun. It then takes on a charge and reaches the part. When the guns are shut off, powder will not be immediately shut down (as with wet spray). If parts are hung closely together on the conveyor line, triggering is not a viable option.

Many powder vendors suggest that virgin powder be sieved prior to use to eliminate any settling, possible fusion, or agglomeration that may occur during shipment. (*Virgin powder* is powder that is still boxed from the manufacturing process and has never been fed through an application system.)

Reclaiming oversprayed powder can yield a material usage of approximately 95%. This is high compared to the wet spray counterpart.

Automatic guns with triggering require fewer application personnel. They are the most economical approach because there is less downtime and gap time between jobs. Compressed air also presents an energy savings.

POWDER STORAGE

Most coating vendors recommend that powder be stored at temperatures below 80° F (27° C) (at 40–60% relative humidity) for not more than six months. (Acrylics are less forgiving and may need air-conditioning.) Actual product may last for years. Keeping the powder in a dry place and making certain each box is properly resealed ensures a quality product next time it is needed. A first-in, first-out written procedure should be implemented. Each box should be marked when it is received.

Always follow the manufacturer's recommendations, procedures, and cautions when handling powder. Powders should be

protected from heat, humidity, water, and contamination with foreign materials, such as other powders, dust, dirt, etc.

Powders must retain their particle size to allow handling and application. Most thermosetting powders are formulated to withstand a defined exposure to heat in transit and storage. This specification varies by type and formulation of the powder, but it can be estimated at 100–120° F (38–49° C) for short-term exposure (not including acrylics with their required lower temperatures). When these critical temperatures are exceeded, one or all of the following physical changes may result:

- The powder can sinter, pack, and clump in the container.
- The pressure of the powder weighing on itself can accelerate packing and clumping toward the container's bottom.

As previously stated, many manufacturers recommend long-term storage temperatures not exceeding 80° F (27° C). Unless the powder is exposed to higher heat, powder that has been stored properly usually can be broken up and rejuvenated after being passed through a screening process. Acrylics start to agglomerate and change chemically at a much lower temperature. Once they sinter, the powder particles may never separate enough to properly fluidize and the particles will surge upon application.

Powders with fast or low-temperature curing mechanisms may undergo chemical changes resulting from exposure to heat. These powders may partially react or be referred to as B-stage. Even if these powders can be broken up, they do not produce the same flow and appearance characteristics as unexposed powders. They have, and irreversibly retain, restricted flow, even to the point of a dry texture.

Powders formulated with chemical-blocking agents to prevent curing below certain trigger temperatures do not typically “B-stage” at temperatures below 200° F (93° C).

Water and powder do not mix when the intent is to spray as a dry powder. Exposure to excessive humidity can cause the powder to absorb either surface or bulk moisture. This causes poor handling, such as poor fluidization or poor gun feeding, possibly leading to gun spitting, surging, and eventually feed-hose blockage. High moisture content causes erratic electrostatic behavior, resulting in

changed or reduced transfer efficiency and, in extreme conditions, can affect the appearance and performance of the baked coating film.

Because powder is a dry-coating formulation, contamination from dust or other powders cannot be removed through sieving or screening (as with liquid paint). It is imperative that containers are closed and protected from plant grinding dusts and other contamination.

Storage-stability properties of powder coatings need not cause problems at the user's facility, provided that a few simple precautions are taken. They are:

- Control the temperature at 80° F (27° C) or less, 50% $\pm$ 10% relative humidity.
- Efficiently rotate the stored powder to minimize the inventory time. Powder should never be stored for a period of time that exceeds the manufacturer's recommendation.
- Avoid having open packages of powder on the shop floor to preclude possible moisture absorption and contamination.
- Precondition the powder prior to the spray application by providing preconditioning fluidization as is available on some automatic systems, or by adding virgin powder through the reclaim system. These techniques break up the powder if minor agglomeration has occurred in the package.
- Maximize the booth's powder-transfer efficiency to avoid problems associated with recycling large quantities of powder.
- Minimize the amount of powder-coating material held on the shop floor if the temperature and humidity of the application areas have been uncontrolled.

Powder Rotation

Some suggestions for successful powder rotation include:

- The powder that is received should be marked and dated on the carton.
- The powder should be used on a first-in, first-out basis, with the date being the determining factor.
- Any powder dated beyond the supplier-recommended shelf life should be destroyed or recertified.

MASKING

Most paint operations require that some parts be masked prior to painting. Powder spray operations are no different. However, the tape used to mask areas is different (see Figure 12-1). Most quality tape manufacturers develop high-temperature tapes that are excellent for use on powder-coated parts sent through a cure oven. These tapes are easily removed after the cure schedule. The price of this type of tape can be justified because powder does not creep under it, and the edges are of good quality.



Figure 12-1. High-temperature tape. (Courtesy Shercon)

There are plugs and caps for most projects. Specialty tape companies can readily mold specialty plugs. Many companies can die cut patterns that would be otherwise difficult to mask (see Figure 12-2). These die cuts make masking much easier and more productive.

Many tape specialty companies sell sample packs. These packs allow a user to see what caps, plugs, or tape will be most effective. Many times, the companies will precut sizes of masking tape. A common size is 0.125–6.000 in. (0.3–15.2 cm) in diameter.

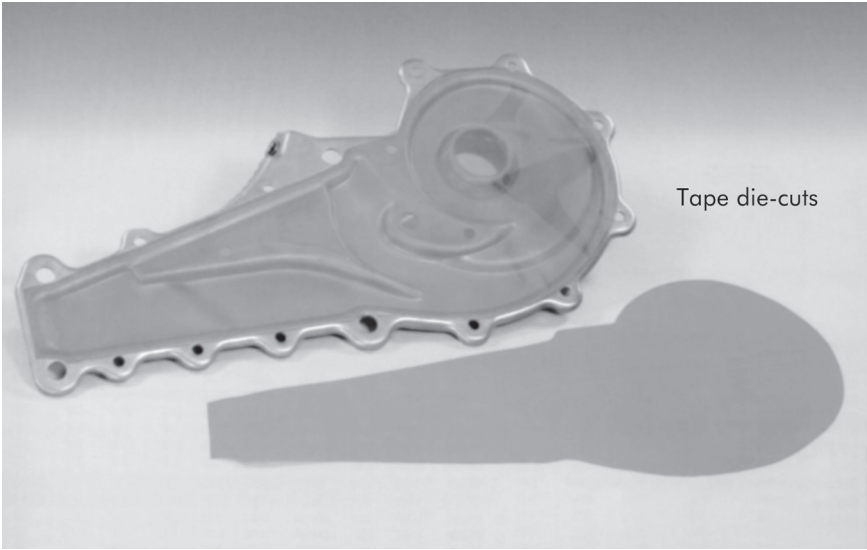


Figure 12-2. Die-cut patterns for masking. (Courtesy Shercon)

Remember that common masking tape will not tolerate the curing temperature needed by powder. To check the temperature tolerance of the tape, run one part through a system and check the outcome.

Clean, Safe, Quality Operations

The definition of *clean* is something each company must decide. Establishing this standard means defining the product quality expectations. It involves evaluating the current or planned condition of equipment, type of facility and air-handling system used, available human resources, and finances. These are factors for establishing realistic criteria, since hospital clean might not be financially feasible or warranted. All cleaning should be performed according to standard operating procedures (SOP) on dates and times determined by a dirt team.

Examples of the definition of clean according to the area include:

- ceilings—no overspray, powder dust, lint, or fibers;
- walls—no overspray, powder dust, lint, or fibers;
- windows—no streaks or overspray on interior or exterior;
- silhouettes—no overspray, powder dust, lint, or fibers;
- spray equipment—no overspray or powder dust; and
- floors—no fibers, paper, or powder dust.

Cleaning removes contamination from an area. Under cleaning and over cleaning add additional cost and they waste productivity.

The desired level of cleanliness for an area reflects several time elements, including:

- the time the part is in the area just prior to the powder application;

- the time the part is being painted; and
- the time the part takes to cure sufficiently so that particulate and fibers cannot attach themselves to it.

The closer the parts are to the paint process, the cleaner the area must be. Areas where powder is applied or where parts cure are the most critical ones in which to maintain cleanliness.

Washing, blow-off, and tack wiping are considered to be part of the paint-preparation process. These tasks should be performed in the same type of environment as paint application environment to ensure that they are as clean as possible before being coated.

DEFINING CLEANING PROCEDURES

Validated cleaning procedures in the form of detailed written SOPs should be used for proper and consistent cleaning. Cleaning personnel should be thoroughly trained in the steps written in the SOP and cleaning practices should be verified periodically.

Cleaning should start from the top and work downward, so as not to redistribute dirt on already clean surfaces. Cleaning patterns should be organized—top to bottom, front to rear—so the work is effective and efficient. Housecleaning and process equipment procedures should follow the same criteria. After these steps are completed, specific job responsibilities and staffing requirements may be established.

A large portion of powder contamination results within the cure oven. Operators should take special care to keep the oven and other related curing equipment clean of dirt and debris.

Steps in cleaning include:

- Clean ceiling, ductwork, and walls with specified cleaners—rinse with water (following the same sequence) to remove residue and neutralize the chemical reaction.
- Clean the floor working from the oven. Following this step, make certain the clean area is not walked on.
- Start the oven and run it for a minimum of eight hours before starting production.
- Run grease panels (or some other tacky panel) through the oven to capture the remaining dirt.

Optimum Cleaning Frequency

Cleaning should be performed according to the SOP or schedule.

If monitored defect levels change for better or worse, cleaning efforts may be adjusted to obtain optimal frequency. Frequency alteration and defect monitoring are used to determine optimum cleaning frequency, without increased staffing or financial burdens.

Examples of typical cleaning functions that can be adjusted are:

- paint booths—cleaned weekly;
- conveyor shrouding—cleaned daily;
- dust control tunnels—cleaned weekly;
- dust control ceilings—cleaned daily;
- silhouettes—cleaned daily;
- spray equipment/hoses—cleaned periodically;
- ovens—inspected weekly and cleaned monthly; and
- conveyor transfers, turns, indexers, etc.—cleaned daily.

Cleaning Verification

Defined personnel procedures and guidelines for controlling contamination in powder-spray facilities are integral parts of a contamination-control program to improve paint quality. In this program, the following processes are important:

- The cleaning process should be verified by daily inspection.
- Visual inspection of the work areas should be conducted and predetermined methods of verification should be adhered to.
- Inspection criteria should depend on the desired level of cleanliness.
- Verification can be accomplished through a dirt-identification program.
- Tracking results through statistical-process control will verify changes in conditions.
- Measured dirt levels found and verified on painted product allow for concentration on areas with the largest potential to add dirt.

Dirt Identification

Dirt identification is primarily done using several types of microscopes:

- 60- $\times$ shop microscope—used for defect analysis on-line;
- stereo microscope—used for lab analysis and photomicroscopy; and
- scanning electron microscope—used for higher magnification analysis.

Dirt analysis tools and microscope accessories include:

- illuminator with dual fiberoptic light pipes;
- polarizing light attachment;
- Polaroid[®], 35 mm, or video camera with monitor and video printer;
- scalpel handles;
- scalpel blades #11 and #15;
- microscope slides;
- clear and two-sided tape;
- jewelers' tweezers;
- sharpened needles;
- scissors; and
- slide-storage cases and photo albums.

Dirt can cause paint defects that are revealed by cutting the part. Two cutting techniques are used in this case. The first, the horizontal cut, is nondestructive and involves cutting the top of the defect off the painted surface. This is the method used most often. The second technique, the vertical cut, is destructive and involves cutting cross sections through the paint layers. By using either technique, the defect is identified and the paint layer, which contains the contaminant, is located.

Dirt Library

The company should establish a library of dirt coatings. This library contains reference samples from every segment of the powder process, as well as defect samples. A dirt analyst uses the li-

brary to compare unknown defect samples to known reference samples to accurately identify the contaminant. A cause-and-effect analysis is conducted and the findings determine corrective action to reduce or eliminate the source of the defect.

A sample from every material in the paint facility should be selected, including samples from gloves, painter caps, solvent wipers, and tack cloths. Samples of sanding dust, washer crystals, paint-rack chips, conveyor dirt, and oven dirt also could be collected.

Dirt reduction in any paint facility is a team effort, encompassing the fundamentals of problem solving, statistics, and dirt analysis. By using the tools of dirt identification and team problem solving, dirt sources are identified, reduced, and eventually eliminated.

ESTABLISHING A CONTROLLED ENVIRONMENT

Operators should be thoroughly familiar with contamination control rules and procedures, always adhere to those rules and procedures, and report any difficulties. In addition to rules, however, controlling the clean room environment involves carefully selecting non-contaminating clothing and efficient wiping cloths.

Wipers, Tack Rags, and Tack Cloths

Static electricity and frictional forces make dirt particles adhere to surfaces with such surprising strength that removing them can be difficult. Solvent wiping is one potential solution to this problem, but this is not practical in some situations. Another solution is to use tack cloth.

Tack-cloth wipers are fabric wipers treated with resins that pick up and hold particulate matter. Tack cloth is a good wiper because it is safe, effective, and easy to use. The problem with older, traditional tack cloths was that resin in the tack cloth was easily transferred to the surface being wiped and could interfere with further processing.

Tack cloths come in bulk-cut or rolls, and traditionally are made from open-woven, absorbent cotton gauze—cheesecloth. Newer types of tack cloths are made with nonfibrous synthetic fabrics.

Treatments of the synthetic provide a permanent “wet-tack,” but vary in quality. A company should use high-quality tack rags because they do not leave residue or contaminants.

Some tack cloths contain volatile solvents, water, oils, thinners, and other materials. These cloths can be inconsistent and may even stiffen or dry as the fluids evaporate. Solvent, oils, and waxes can leave invisible residues that may react to a finish to cause marring, fisheyes, holidays, and other coating defects.

When buying tack cloths, a manager should take time to look at how they are made and the products in the cloth. Cheaper is not better when it comes to a good wiper or tack cloth. Wiping with a cloth that leaves behind water, naphtha, alcohol, or other liquids facilitates accumulation of dirt, increases attraction of airborne particles, and can leave a residue that interferes with finishing.

In many paint operations, it is necessary to use auxiliary methods to ensure the part surface is completely clean of fingerprints or contaminants that reach the part after the pretreatment wash. There are a number of cloths and wipers on the market.

The two common solvent wipers are:

1. dry wipers, manually saturated with a solvent for a specific application; and
2. presaturated solvent wipers.

Dry Wiping

Dry wiping involves manually wiping a product’s surface with a wiper designed to suit a specific need. Cleanliness of the wiped surface is key, and the wiper of choice is the one that best performs this function for a specific application, regardless of its characteristics. It should be kept in mind that wiping is a low-quality method that is used only for limited or low production rates.

Tack Off

Tack off involves manually wiping a product’s exterior surface, and some interior surfaces, with a specially prepared wiper, usually called a tack cloth or tack rag. The criteria for tack-cloth selection are:

- Durability of the tack cloth when used on various surfaces—rough surfaces can cause the wiper to fray, depositing fibers onto the wiped surface.
- Dirt-holding capacity—the ability of the tack cloth to contain contaminants within the wiper.

Used properly, the non-marring tackifier should not leave any residue on the cleaned surface. This often requires significant operator training on how to use the tack cloth.

The four types of wipers are:

1. woven—interlacing two sets of yarns, warp, and filling, so they cross each other at right angles to form the cloth;
2. knits—constructing fabric by interlocking a series of loops of one or more yarns to form the cloth;
3. nonwovens—using mechanical interlocking, an assembly of textile fibers in a random web or mat are held together by fusing the fibers or bonding with a cementing medium to form the cloth; and
4. polypropylene fabric—a melt-blown, thermally bonded fabric with low-particle and fiber generation.

Selection of a wiper depends on the durability of the wiper when used on various surfaces. Some surfaces to be cleaned can be rough and might fray a wiper. This would deposit fibers onto the wiped surface.

An operator should keep in mind the following about presaturated wipers:

- Process control—presaturated wipers ensure that the wiping process is performed in the same fashion each time.
- Environmental awareness—by eliminating solvent cans and excessive solvent use, presaturated wipers greatly reduce needless evaporation of volatile organic compounds.
- Safety—wipers eliminate the need for in-plant mixing, transfer of solvents, and open solvent containers.
- Flexibility—several different wiping materials can be combined with customer-specified solvents to solve specific application problems.
- Economy—saturated wipers are economical because they reduce solvent and handling times and offer increased efficiency in cleaning operations.

- Sorbent properties—this is the wiper’s ability to readily accept and hold a solvent.
- Dirt-holding capacity—this is the wiper’s ability to absorb contaminants.
- Solvent resistance—avoid wipers needing special coatings and wipers held together with resins that certain solvents degrade.
- Wiper-edge integrity—wiper edges should be engineered to avoid potential degradation and subsequent spread of fibers.
- Integrity of the body of the wiper—the body should be engineered to avoid self-particulation under wiping action.

Clothing Policies

Clothing policies should be established and staff should adhere to them. In the clean room, clothes with limited linting should be worn. Clothing must be kept from contamination by plant or outside environments. A dressing and “blow-off” policy should be established. Clothes-changing facilities should be provided adjacent to the clean room with blow-off protection from the outside environment.

Personal Hygiene Products, Cosmetics, and Jewelry

A daily shower removes powder remnants. Hands should be washed and dried before leaving the locker room. Hair should be clean and well-groomed and facial hair should be contained where possible. As with most jobs, an employee should come to work in a healthy condition. Poor health and physiological problems can interfere with desired performance in a controlled environment.

Wearing antiperspirants, cosmetics, and other personal hygiene products may cause powder-coating defects. Those products that have been tested and shown to cause defects should not be used. Generally, eye shadow, lipstick, blusher and powder should be discouraged because it will limit the amount of particle contribution from the operator. Rings, bracelets, and wristwatches should be covered if these items are necessary.

Personnel—regardless of job duties or positions—should wear limited layers of clothing when entering the clean room. Apparel

and ancillary items not recommended for wear in a controlled environment—such as coats, jackets, and jewelry—should be removed and stored in designated places in the locker room.

Clothing Worn Under Limited-linting Garments

Clothes made from synthetic fibers, such as polyester, are preferred to those made from natural fibers like wool and cotton. Apparel should not be torn and should be free from metal fasteners like rivets that could scratch a finish. Belt buckles should be covered.

Gowning should take place in a gowning room and include lint-free coveralls, lint-free headgear, gloves, respirators, and eyewear or eye protection where and when required. The gowning room should be clean (especially the floor), and stocked with coveralls, hoods, boots and/or shoe covers, caps, and tacky mats. Items should be checked for physical damage before each use.

A top-to-bottom gowning sequence for paint-booth operators is recommended:

1. Don limited linting headgear.
2. Put on the coverall, making sure it does not touch the floor. The zipper must be fully closed to the top of the neckline and covered by the zipper flap. The coverall zipper should be closed and fully snapped to the neck and closures at wrists and ankles should be fully secured.
3. Don shoe covers, if used.
4. Place the respirator over the mouth and nose. If a fresh-air-helmet system is used, it may be impossible to don until the operator enters the spray booth, where the helmet can be connected to a fresh air supply.
5. Don protection for the eyes, if used.
6. Put on gloves by touching gloves only in the cuff area, making sure the fingers are not contaminated.
7. Enter the paint area. If using an air shower, enter through the air shower turning 360° at least once with arms raised.

Since the same apparel may be worn for an entire day, it needs to be removed for breaks and lunch and stored in a clean, designated area. Shoe covers may be contaminated with powder when

a worker leaves the spray booth. If this is the case, the shoe covers should be removed to prevent tracking powder over the floor and back to the gowning room.

After entering the gowning room from the paint area:

- Gloves are removed and discarded.
- The fresh air helmet or respirator is removed and stored in a designated area for reuse.
- The coverall is unzipped, carefully removed (without touching the floor) and prepared for storage or returned to the laundry.
- Headgear is removed and stored or returned to the laundry.
- Apparel to be laundered is placed in proper containers.

Paint-spray Apparel

The primary purpose of clean-room apparel is to control and contain particles and fibrous contaminants generated both inherently and by the wearer. Characteristics of the apparel that may influence its performance include design, construction, electrostatic properties, durability, and comfort. The functions of a proper garment are:

- protection from paint,
- protection of production-part surfaces from human contamination,
- electrostatic control relevant to minimizing contamination of part surfaces, and
- comfort and ergonomics.

Generally, washable fabric garments are made of continuous multifilament polyesters that can be manufactured with carbon-suffused conductive fibers to control static electricity, thereby minimizing turboelectric-charge attraction of contaminating particles and fibers. Many varieties of weave and density are compatible with powder-spray environments. After choosing the type and characteristics of the multifilament polyester required, the user should consider construction and design characteristics. Good construction characteristics that maximize barrier performance include:

- Cut fabric edges are overstitched or serged prior to garment assembly.
- A minimum number of seams are present, created by employing a double-needle, flat-felled seam, or other acceptable edge-joining techniques to enclose fabric edges.
- Needle holes approximate thread diameter as closely as possible to limit particle pass-through in seams, cuffs, zippers, and any exposed surfaces.
- Zippers of brass or a clean-room composite material are used, such as a polyester coil with unpainted nickel-pull slides. Zippers covered by a fabric overflap limit particulate pass-through and prevent paint mutilation.
- Where garment snaps are used, concealed stainless-steel snaps are suggested. It is recommended that hook-and-latch style enclosures not be used and that materials be free of silicone.

Threads used to make the garment should be continuous multifilament polyester and be free of available silicone. A purchaser should avoid extraneous design features in the garment that could produce unnecessary particle entrapment. These include pockets, tool loops, pen tabs, and vented panels.

Choices and variations of woven polyesters are extensive. Paint room (clean room) operators should study facility needs before making decisions on fabric and design requirements. Following these decisions, a manager should thoroughly investigate the selected garment manufacturer. This includes site audits. If garments are purchased, leased, or rented through an industrial clean-room laundry, the manager should insist on knowing where the garments are produced. In this case, the laundry and garment manufacturer should be investigated for adherence to clean-room garment construction and laundering precepts, as well as pertinent quality controls.

In the paint industry, companies use a rating system to determine how their end parts should appear. The paint finish is given a rating from A to D. A rating of "A" means that the part must look its best. For example, automotive topcoats are considered "Class A" finishes. A rating of "D" means the part requires paint to protect it from some form of the elements. There is no one rating for all companies. Each company sets its own specific rating, then

follows its rules. A Class A rating means there cannot be major inclusions on the part's surface. The finish must be contaminant free with no sags or runs. A Class A rating means all necessary precautions have been taken to eliminate any contributing factors that allow contamination within the application area and/or on the part being finished.

If a facility needs the best in clean-room apparel, certificates from the manufacturer should state that the garment is made from Class A, clean-room material and constructed in a Class A environment. Many companies cannot provide this documentation. The laundry should be equipped with, or be able to demonstrate, that:

- A controlled environment has been established at a cleanliness level consistent with the desired garment. Preferably, the controlled environment (clean room) and gowning airlock area should maintain a prespecified micron-particulate rating.
- Pass-through washer/extractors with stainless steel drums and welding are used and dedicated to laundering limited-linting garments. Wetted components of the clean-room washer/extractor should be nonparticulating and noncorrosive.
- Washing efficiency is pertinent to effective paint, pigment, particle size, and fiber control.
- Washing chemistry and temperatures are compatible with the fabrics being laundered to avoid chemical degradation that destroys fabric and results in inherent particulate and fiber generation.
- Dryers are equipped with stainless steel drums and retrofitted to accommodate dedicated high-efficiency particulate filtration.
- Relevant particulate, fiber, and silicone-free packaging is used in a controlled environment to limit unwanted contamination. Typically, this is a polyethylene bag, burped of air and heat sealed with evidence that the seal is inspected for complete and uniform closure.
- Clean, polyethylene-lined, and sealable transport containers made from puncture-resistant material are used for packaged garments.

- Determinable process controls and defined logistics (SOPs) are incorporated in garment processing, testing, wear, repair, cycling, and record keeping.
- Appropriate testing equipment and procedures determine cleanliness expressed in terms of releasable or available particulate and fibers.

Limited-use disposable garments are manufactured in a variety of grades depending on intended use. It is important to match the type of garment to personnel protection and clean-room needs. As in the case of other garment systems, disposable garments should always be laundered before use.

Particles and dirt from shoes and wheels represent a major threat to the integrity of clean rooms. This threat can be controlled with contamination controls, mats, and flooring.

Gloves

Gloves are the most overlooked part of clean-room clothing, but they are probably the most important part because they are usually the only clothing actually in contact with manufactured components. It is extremely important to choose the correct glove for a specific clean-room application. Glove types include polyester, stretch laminate, latex, vinyl, nitril, and butyl. Only powder-free gloves should be used.

The manufacturer of clean-room gloves should follow the guidelines previously presented for reusable garments. Gloves of proper length ensure no exposure of bare wrist or hands. Note, however, gloves for powder sprayers must allow skin contact with the spray gun to ensure proper operator grounding. In addition, under-gloves, or glove liners for use with latex or vinyl, offer greater worker comfort.

COMPRESSED AIR

The compressed-air system supplying processed air to the paint booth cannot be overlooked in evaluating potential contamination. In addition to conveying paint to the work area, compressed

air blows dirt off parts prior to coating, and provides power to powder mixers and powder-conveying equipment. It also fluidizes the powder coat. The compressed-air supply, common to most painting, can potentially introduce solid particles, oil aerosols, and liquid or excess water vapor into the paint-booth environment.

Specifying coalescing filtration and a dryer at the point of use is a good start to avoiding problems. Coalescing filters have a submicronic pore structure, causing oil and water aerosols to combine or coalesce into liquids that drain into the filter bowl at the same time the filters provide particulate filtration. Operators should specify a high-quality air-compressor filter system above 19.685 $\mu\text{in.}$ (0.50 μm).

Most production-paint spraying relies on compressed air to convey the paint, whether it is solvent, water-based, or dry powder. The compressed air carries paint from container to applicator and then to the item being painted. The air should have less than 0.1 ppm oil and a dew point of less than 35° F (2° C).

It is essential that compressed air be of the highest quality, meaning that it must be clean—free from particulates large enough to cause blemishes or damage application equipment. The air must be oil-free and dry. It should have a pressure dew point lower than the coldest area in the plant, sometimes including out of doors, to prevent condensation. Specifying an oil-free compressor does not guarantee that air reaching the painting operation is free of oil aerosols.

Contaminants

Contaminants in a compressed-air system usually consist of particulate, oil aerosols, and water in liquid, aerosol, and vapor forms. Additional contaminants can plague an air system, and are particularly a concern if the compressor-air inlet is improperly located. For example, the air inlet must not be situated where vapors from a solvent-based painting operation can be ingested. In addition, ingested vapors and soot from motor-vehicle emissions can cause air-system problems that are difficult to diagnose and control.

External particulates enter the compressed-air system through the compressor-air intake. Although an intake filter is generally employed, it typically is insufficient to supply the compressor with air that is clean enough to power a powder-coating operation. In addition, the intake filter is an easy item to neglect in all but the most thorough preventive-maintenance programs.

Internally generated particulate comes from the compressor itself, and from ancillary equipment associated with creating the compressed-air supply. Desiccants in air dryers are a common source of such particulate.

Piping that distributes compressed air is a major source of particulate. Easily seen particles, such as rust and pipe scale, are only a small portion of the total dirt generated by older pipes. Most particles, by weight, in an air system are in the 19.685 $\mu\text{in.}$ - (0.50- μm) size range. Water condensing on the inside of the pipes worsens the situation, promoting rust and deterioration.

Air Compressors

Air compressors come in many different types, sizes, and configurations. Virtually any type of compressor can power a paint-spray operation if the proper conditioning equipment is added at the outlet.

Oil-less compressors use self-lubricating bearings and exotic materials like Teflon[®] composites to provide low-friction surfaces within the compressor, requiring no additional lubricating oil. Oil-aerosol emission from oil-less compressors is much lower than from oil-lubed compressors; but, in most installations the compressor condenses ingested ambient-oil vapor and emits it as an aerosol. In addition, oil-less compressors are more expensive to purchase and maintain than their oil-lubricated counterparts.

Oil-lubricated compressors have a reservoir of lubricant that is splashed, pumped, or injected onto the moving surfaces of the compressor to provide lubrication, cooling, and sealing. A small amount of lubrication oil reaches the compressor outlet in the form of oil aerosols.

The compressor at the air intake ingests oil aerosols and vapors, but the most common cause of oil contamination in a compressed-

air system comes from the compressor crankcase or oil-injection system. Although many compressors employ an air/oil separator to reduce oil aerosols at the outlet, the average compressor has the following typical oil-aerosol-emission levels:

- screw compressor = 25–75 ppm;
- reciprocating (piston) = 5–50 ppm; and
- centrifugal = 5–15 ppm.

While 25 ppm sounds insignificant, a 100 ft³/min (2.8 m³/min) compressor, with an outlet concentration of 25 ppm, puts almost 7 oz (198 g) of oil into the compressed-air system every 35 hours.

Depending on the operating environment, even an oil-less compressor can have 2–10 ppm of oil aerosols at the outlet. In general, oil vapors do not seem to affect liquid-paint-application systems, but some powder paints may be sensitive to contact with oil vapors. Activated-charcoal-filter elements or beds can remove oil vapors from the compressed-air supply.

Water, as a contaminant, can be found in four different forms in an air supply:

- Liquid water appears as condensation; compressed air leaves the outlet of the compressor and begins to cool in the pipes.
- Liquid in the air supply can cause system damage and poor application performance.
- Water aerosols are an agglomeration of water molecules that travel suspended in the compressed-air system. Atmospheric fog and steam that rises above boiling water are examples of water aerosols. Water aerosols combine to form liquid water.
- Water vapor is present in atmospheric air. When compressed, the relative humidity of the compressed air is usually at or near 100%. This means that any additional cooling that occurs in the compressed-air-distribution system causes the water vapor to condense into liquid water.

Additional drying capacity—usually achieved with a heated, regenerative desiccant air dryer—can reduce the pressure dew point to manufacturer-specified levels for applying powder paint.

Aftercooler

An aftercooler (either air-air or liquid air) should be connected to the outlet of the compressor to cool the air to a temperature close to or below the ambient air temperature of the factory or shop. Many larger, packaged air compressors include the aftercooler. As the compressed air is cooled in the aftercooler, much of the water vapor condenses into liquid and drains away. The aftercooler outlet air is still saturated with water vapor, and it condenses in the piping if allowed to cool further.

Air Dryer

An air dryer is highly recommended for air systems that supply spray-paint operations. Appropriately sized refrigerated dryers can lower the pressure dew point of the compressed air to near 35° F (2° C), but when low dew points are required, a twin-tower desiccant dryer is usually indicated. Desiccant dryers can routinely achieve lower than a -40° F (-40° C) dew point if sized properly. Powder-paint application systems may require even lower pressure dew point temperatures with some powders. Air dryers require proper filtration—both before and after the dryer—to run at peak efficiency.

Filtration

Filtration is of great importance in the compressed air system because a correctly specified filtration solution can protect application equipment and the products being painted from failures of other portions of the compressed-air delivery system. Effective filtration can reduce the effects of system upsets such as startups, blowdowns, dryer failures, and other abnormal air-line events that can cause expensive and frustrating paint application problems.

Surface filtration media include metal or plastic screens, and thin paper, metal, or plastic (even Teflon[®]) sheets or membranes. Surface-filtration media traps particles by straining—preventing those particles larger than the pores in the media from passing through.

Depth-filtration media include felts, bulk-fiber-filled cartridges, sintered plastic, ceramic, or metal-filter elements, and rolled cellulose. They also include glass-fiber-paper elements and cast- or vacuum-formed glass-fiber coalescing filters. Depth-filtration medias rely on impingement, interception, and diffusion to remove particles and coalesce aerosols.

Screens have limited use in compressed-air systems, as most particles in an air system are below 39 μm . (1 μm) in size, and typical metal and plastic screens have absolute particle retention ratings in the 0.0008–0.0047 in. (20–120 μm) range.

Sintered metal, ceramic, and plastic filters are made by using heat and pressure to melt the surfaces of small spheres together, creating a porous solid—the smaller the spheres, the smaller the pore size. Sintered-filter media rated below 39 μm . (1 μm) are rare. Although sintered-filter elements with larger pore-size ratings are used extensively in compressed-air systems, their effectiveness in combating contaminants that plague spray-painting installations is limited.

Cellulose-based paper filters, usually pleated to increase available surface area, are a popular filter medium in compressed-air applications. The smallest cellulose fibers are limited to around 0.8 μm . (2 μm) in diameter, so the tightest standard cellulose paper filters do not have good retention efficiencies below 39 μm . (1 μm). In addition, cellulose paper filters usually lack the thickness necessary for oil-coalescing efficiency in the 0.0390–7.8700 μm . (0.001–0.200 μm) oil aerosol-size range.

High-efficiency particulate air (HEPA) filter media are paper made from borosilicate micro-glass fibers, and, by definition, have an efficiency rating of 99.97%. This test uses aerosols with particles in the 7.87–23.62- μm . (0.2–0.6- μm) size range generated by vaporizing and condensing dioctyl phthalate (DOP).

Cast micro-formed coalescing filters, like HEPA filters, are typically made from fibers, but rather than rolling multiple layers of paper, the elements are formed using a vacuum process to a thickness (or depth) that optimizes coalescing efficiency without sacrificing flow in favor of differential pressure performance. The advantage of vacuum forming the glass filter medium is that a graded porosity characteristic is built into the filter medium and

the particulate retention efficiency (mean pore size) can be controlled for different filtration applications.

Coalescing filters. Coalescing filters combine oil and water aerosols into liquids for easy removal from the compressed air system. They have the small pore size required for combining aerosols into liquids. Excellent high-efficiency particulate filters are available in the 39.37–393.70 $\mu\text{in.}$ (0.1–1 μm) particle-size range.

Coalescing means joining together to form a larger whole. Coalescence of oil and water aerosols is a steady-state process. This means that a properly designed—and applied—coalescing filter continues indefinitely to combine oil and water aerosols into liquids with high efficiency. The particulate that a filter traps is the only limit on the filter's life.

Graded porosity refers to changes in the effective pore size of the filter medium at different depths. If the effective pore is larger at the entrance of the filter medium, and gets progressively smaller deeper in the fiber bed, the dirt-holding capacity of the filter element is maximized, increasing the life of the element.

Effective coalescing filter elements usually have the following physical characteristics:

- Most require additional support structures, usually cylindrical metal or plastic retainers, to survive the rigors of the compressed air system. The glass fibers are bound with different types of binders, depending on the application, but the strength of the fiber/binder matrix cannot compare to that of a sintered stainless steel filter element or a metal screen.
- Most use a drain layer on the outside of the filter element—assuming that the air flow direction is inside to outside. This filter element catches liquid oil as airflow moves it through the elements. The drain layer is made of a coarser material, allowing gravity to pull the oil to the bottom of the element and drain it.
- Coalescing filters allow extremely high oil-removal efficiencies of over 99.99%. Using the example given earlier, where 7 oz (198 g) of oil was being passed into the compressed air system every 35 hours, if a coalescing filter with an efficiency of 99.97% were employed, only 0.0021 oz (0.060 g) of oil would be introduced into the air system every 35 hours. Using two

coalescing filters in series yields tremendous efficiency. From a practical standpoint, using the filters in series provides extra protection in cases of system upset.

- By placing a high-efficiency coalescing filter as close as possible to the paint application system, additional protection is gained. This step ensures that contaminants created by the piping system do not reach the paint process. In addition, point-of-use filtration protects against system upset and other compressed-air distribution system problems. These problems may be outside the control of the area or department responsible for the painting operation. Protecting the powder-paint equipment at this point can be a huge benefit. Contamination of powder equipment can result in loss of powder in the system, extra labor costs to clean the equipment, or loss of parts not being painted during maintenance of the system.
- True coalescing filters (filters based on borosilicate micro glass) are not cleanable. Back-flushing accomplishes little or nothing, but causes reduced efficiency upon restart and oil re-entrapment.
- Coalescing filters are not indestructible, so precautions should be taken to ensure that full line pressure is not placed across the filter element. Lockout valves with built-in vent ports should be used with caution, as it is possible to cause reverse flow (and reverse differential pressure) through a coalescing filter. Most coalescing filters are not as strong in the reverse-flow direction as they are in the forward-flow direction.

Operators should specify silicone-free coalescing element construction and ask the manufacturer or distributor to certify it in writing.

Proper sizing of the coalescing filters is important. Undersizing to save initial cost increases velocities through the element—reducing coalescing efficiency, and accelerating the element replacement schedule. Oversizing filters is suggested if inlet oil or dirt concentrations are high, but some manufacturers warn that overall coalescing efficiency can suffer if velocity is too low through the element.

Measuring differential pressure with respect to time can plot the dirt-loading characteristics of a high-efficiency, depth-loading filter. Usually, the filter builds differential pressure slowly at first, then increases exponentially. By monitoring differential-pressure gages, maintenance personnel can accurately predict when a filter will become plugged.

When a coalescing filter is working normally, there is a portion of the filter element that is constantly wet with oil. This wet zone at the bottom of the element is the result of capillary action and additional liquid oil drained from the remainder of the filter element. If the flow rate is reduced, the wet zone grows higher, but if the flow is increased suddenly and appreciably, oil can blow off the wet zone and re-enter the air stream.

Operators should beware of coalescing filters that are of bulk fibrous material stuffed into a cartridge. Testing has shown that, when dry, these filters are efficient at soaking up oil and water. But once oil-wetted, their efficiency drops dramatically, with no warning to maintenance personnel that the filter is no longer protecting the powder-paint operation.

Rating methods for compressed air filters vary among manufacturers. There are standards being written in the United States as well as in the European community that will assist the enduser in verifying the performance of the coalescing filter for mission-critical applications such as powder-coating installations.

One characteristic shared by mechanical filters is that differential pressure is generated as the flow rate through the filter assembly increases. Coalescing filters tend to have a higher initial differential pressure, per unit area, than lower-efficiency, absolute-rated particulate filters. Media thickness, necessary for efficient removal of the smallest aerosols via diffusion, contributes to the differential pressure. A balance must be struck between efficiency and differential pressure. Once the coalescing filter is wet with oil, additional differential pressure is required to move the same amount of air through the filter. Operators should review the rated airflow and ask about the dry and wet differential pressure ratings of a coalescing filter. Manufacturers can provide test data and discuss the differences between wet and dry pressure drop.

Particulate removal efficiency refers to the percentage of particles removed by the filter within a particular size range.

Absolute filter media, like screens and membranes, have published ratings for the largest particle passed. For instance, a 118 $\mu\text{in.}$ (3 μm) absolute membrane filter will retain 100% of the particles 118 $\mu\text{in.}$ (3 μm) and larger.

Coalescing filters are usually rated for filtration efficiency over a range of particle sizes. For example, a coalescing filter may be rated at 99.99% efficient at removing 4–12 $\mu\text{in.}$ (0.1–0.3 μm) particles. This is primarily due to the methods employed in testing coalescing filters, as well as the nature of the fiber-based, depth-type filter medium. Unlike woven screens or photo-etched membranes, glass-fiber-based coalescing filters do not have exact pore sizes, although the manufacturing process can be controlled to yield an average pore size.

The efficiency test for dioctyl phthalate (DOP) was originally created to verify the performance of HEPA filters. The DOP test relies on the 12–24 $\mu\text{in.}$ (0.3–0.6 μm) oil aerosols that are generated by heating DOP oil. This test is used today to evaluate coalescing filters. It is a fairly good indicator of real-world performance because the DOP aerosols are oil-based and in the size range of lubricating oil aerosols found in standard compressed air systems.

A more recent test procedure for coalescing filters uses actual compressor oil and an aerosol generator to provide the required 12–24 $\mu\text{in.}$ (0.3–0.6 μm) aerosols. Unlike the DOP test, the coalescing efficiency test is performed at working pressures (60–100 psi [414–689 kPa]) to more accurately simulate actual conditions. Some coalescing filter media manufacturers use this test procedure to verify published specifications and control the quality and consistency of their coalescing media.

SAFETY

A company cannot meet safety standards simply by putting clothing and respirators on its employees. The OSHA general industry standard for respiratory protection (29 CFR 1910.134) requires that an employer establish a respiratory protection program

when effective engineering controls are not feasible. Booth designers should keep the following in mind:

- OSHA does not want to see employees suited and wearing respirators. The agency would rather see equipment designed to eliminate the need for respirators.
- OSHA may inform a manufacturer that a powder-spray booth should be properly designed to eliminate the need for respirators or protective apparel.
- The agency will ask manufacturers to investigate various methods to change powder booths. Only if the cost is excessive will OSHA look at respirators as an alternative.
- OSHA states that a substantial investment needs to take place to show a commitment to bringing the application booth within OSHA specifications, which is then monitored by particulate counts.
- If the booth cannot be feasibly corrected, OSHA permits a user to initiate a respiratory-protection program.

Guidelines in the protection program help reduce employee exposure to occupational dusts, fumes, mists, radionuclides, gases, and vapors. (Powder is considered a nuisance-dust particulate.) The primary objective is to prevent excessive exposure to these contaminants. Where feasible, exposure to contaminants is eliminated by:

- engineering controls,
- general and local ventilation,
- enclosure,
- isolation, and
- substituting a less hazardous process or material.

When effective engineering controls are not feasible, use of personal respiratory protective equipment may be required. The following should be kept in mind about respirators:

- An operator should never feed a painter's respirator from air coming directly from the air compressor outlet port.
- Any aerosol or vapors that might bypass a filtration system will injure the painter.
- With respirators fed from plant air compression, the air first must be passed through a monoxide detector.

- It is the employer's responsibility to provide proper respiratory protective equipment to meet the needs of each specific application.
- Employees must be trained to use the equipment.

Management

Superintendents, supervisors, forepersons, or team leaders of each area are responsible for ensuring that their personnel are completely knowledgeable of the respiratory protection requirements for the areas in which they work. Management also is responsible for ensuring that employees comply with the respiratory program—including respirator inspection, use, and maintenance.

Employers should select and approve respirators. Selection is based on the physical and chemical properties of the air contaminants and the concentration level likely to be encountered by the employee.

Employees

Employees are responsible for being aware of the respiratory protection requirements for their work areas. They are responsible for wearing the appropriate equipment according to instructions and for maintaining clean and operable equipment.

Respirator Inspection and Maintenance

The following points should be considered for respirator inspection and maintenance:

- The wearer of a respirator must inspect it daily whenever it is in use. Figure 13-1 shows a typical respirator.
- The supervisor must periodically spot check respirators for fit, usage, and condition.
- The assigned employee must clean respirators on a daily basis that are not discarded after one-shift use. He or she should do this according to instructions from the manufacturer or the person designated by the respirator program coordinator.

- Respirators must be stored in a suitable container away from areas of contamination.
- Whenever feasible, respirators must be marked or stored in a way that ensures they are worn solely by the assigned employee. If use by more than one employee is required, the respirator must be cleaned and disinfected between uses.

Each area requiring regular use of respirators must maintain a logbook. Employees not discarding respirators after one shift should sign this logbook daily to document inspection and maintenance of their respirators.

Hazards

Most powder coatings contain a variety of substances to formulate the ultimate coating material. Some may pose health hazards to personnel within the immediate spray area. Pigments, curing agents, polymers, and fillers present potential health hazards if



Figure 13-1. Typical respirator.

permitted to escape the spray containment area. Improper ventilation or improper handling or use of powder causes such hazards. OSHA regulations, which apply to both paint user and supplier, govern the handling and use of powder coating. A materials safety data sheet (as shown earlier in Figure 1-2) must be provided by the supplier, advising the user of any hazards associated with the powder coating material. Recommended precautions concerning skin contamination and respiratory exposure are normally documented on the materials safety data sheet.

The following recommendations should be considered to reduce potential health hazards associated with powder coating materials:

- Personnel involved in handling powder should wear gloves and dust masks. These are needed when opening fresh material containers, dumping material into supply hoppers, cleaning or performing maintenance on equipment, or disposing of empty material containers. Powder can dry skin exposed to it for extended periods of time.
- Facilities should be provided for proper washing, with soap and water, of skin exposed to powder materials, and personnel should be encouraged to wash frequently—especially before eating, drinking, or performing bodily functions. Skin reactions to powder can occur in some cases, and should be treated by frequent washing. Cleaning the skin with organic solvents should be discouraged.
- Respirators or masks help prevent powder inhalation, as does proper ventilation of the powder spray system. Proper ventilation maintains an environment safe from explosions by minimizing the possibility of ignition sources (National Fire Protection Association [NFPA] 33 specifies proper ventilation guidelines). The safest operating procedures specified for powder spray applications also are the most productive.

Safety should always be incorporated into operating and maintenance procedures for the powder coating system. These procedures should cover all aspects of operation, including:

- storing and handling of powder materials;
- spraying parts within the spray booth;
- conveying parts through the spray booth;
- cleaning and maintaining equipment;

- troubleshooting equipment;
- system startup and shutdown;
- reading, calibrating, and setting control gages and regulators;
- recording daily critical ventilation-pressure readings;
- responding to alarms, interlocks, and system safety-oriented control devices; and
- disposing of waste materials.

Spray areas should be provided with mechanical ventilation adequate to transport flammable or combustible dusts, vapors, mists, residues, or deposits to a safe location. Ventilation for spray booths should be adequate to always confine air-suspended powder to the booth and recovery system.

Average air velocity through electrostatic booth openings should not be less than 100 ft/min (30.5 m/min). Other safety steps to be taken include:

1. Parts being coated should be supported on conveyors or hangers properly connected to the ground (the earth), with a resistance of 1 mega-ohm or less.
2. Electrically conductive objects in the spray area, except those objects required by the process to be at high voltage, should be adequately grounded.
3. Spray areas must be protected with an approved automatic fire-extinguishing system.
4. Fixed-automatic powder-application equipment should be protected further by an approved flame detection apparatus that will, in the event of ignition, react to the presence of a flame within one-half second and:
 - Shut down energy supplies (electrical and compressed air) to the conveyor, ventilation, application, and transfer and powder-collection equipment.
 - Close segregation dampers in associated ductwork to interrupt airflow from application equipment to powder collectors.
 - Activate alarms.

Powder coatings contain polymers, curing agents, pigments, and fillers requiring safe operator-handling procedures and conditions. Pigments may contain heavy metals, such as lead,

mercury, cadmium, and chromium. The handling of materials containing such elements is controlled by OSHA regulations. End use may be restricted according to Consumer Product Safety Commission regulations.

5. Under some circumstances, OSHA requires the applicator to inform employees of the hazards associated with handling certain components of powder coatings. The applicator is advised to obtain this information from the supplier in the form of a materials safety data sheet. Powder coatings should be handled in a manner that minimize skin contact and respiratory exposure and are consistent with particular materials safety data sheet recommendations. Obvious health reactions attributed to any powder coating should be referred to a physician as soon as possible.
6. Opening, emptying, and handling powder containers such as boxes and bags often present the greatest worker exposure to risk, even with well-designed systems. Engineering practices, personal protective equipment, and good personal hygiene should be used to limit exposure. In a well-designed spray operation, there should be negligible exposure of employees to dust.
7. Powder coatings—because of their fine particle size and frequently large percentage of TiO_2 —will absorb moisture and oil readily. Powder left in contact with the skin for extended periods tends to dry out the skin. To prevent this, workers should wear gloves and clean clothing. Hot skin and perspiration, combined with the abrasive characteristic of powder material, escalates the chance of reactions to powder. Operators of manual electrostatic guns must be grounded. To prevent carrying powder away from work, employees should change clothes prior to leaving the workplace. If powder gets on the skin, it should be washed off at the earliest convenient time, at least by the end of the day. Workers who show skin reactions to exposure from powder must be especially careful to wash frequently. Washing the skin with organic solvents is an unsafe practice and should be forbidden. Generally, cleansing with soap and water is the appropriate hygienic practice. Additional information should be obtained from the supplier's materials safety data sheet.

These guidelines are directed more toward safe operation of a powder coating system than toward a productive operation. However, as stated earlier, the safest operations generally are also the most productive.

VACUUMS

The nature of powder requires that powder operations have vacuum cleaners to clean waste from areas outside of the booth, such as powder that has migrated out of the ends of the booth or through manual gun doorways. Powder also spreads from the feed hopper and where maintenance is being done on powder equipment.

Vacuums come in two types: electric and pneumatic. Table 13-1 compares both types. Generally, electric vacuums are not used because their motors could cause explosion. Pneumatic vacuums are the vacuums of choice for powder applications because air is readily available.

While powder coating is extremely efficient, cleaning up the ultra-fine particles has always been a difficult job. Powder accumulation on shop floors and inside booths has forced companies to find new ways to meet environmental and worker safety regulations.

Vacuums used in the powder application room should have a high filtration level, so spent air is not contributing to room contamination. The vacuum and its equipment should be regularly emptied and the main filter cleaned of powder so blinding does not occur.

A company should buy a vacuum with better-than-average static lift. Many times, powder, once deposited, acts as a magnet and is difficult to remove from the surface. For this reason, most powder operations paint their floors with high-gloss paint. Gloss floors have a more concentrated chemical makeup than do semi-gloss or matte floors, which trap powder particulate in the surface.

Vacuums bought for powder operations never should be used outside of the powder operation. When purchasing a vacuum, a company should look for the following:

Table 13-1. Comparison of Pneumatic (air) vs. electric vacuums

Pneumatic (Air) Operated	Electric
Non-electric, can be used in hazardous locations.	Arching, brush-type motors not recommended for paint booth area.
No moving parts, nothing to wear out or burn up. Vacuums last for years.	Frequent motor burn-out; entire vacuums must be replaced on a regular basis.
Grounded vacuum, hose, and attachments can be used in any environment.	Ungrounded systems cause static shock to operators and potential explosion.
Two-stage filtration system; all materials stays in tank or drum liner; nothing is emitted to the room.	Inadequate small cartridge filter is the most common complaint, exhausting powder back into the room.
Two to three times the recovery rate of electric units.	Brush-type motors do not produce sufficient recovery.
Quiet operation at 80 dBa.	Electric high-speed units operate between 85-90 dBa.
Compressed air available in the powder booth area.	Single-phase power not always available.
Optional central vacuum available.	Most shop vacuums will not operate with more than 15 ft (4.6 m) of vacuum hose.

- A vacuum should use plant air; the air system should be robust enough to provide air for the vacuum as well as other equipment at the same time. Air fittings should be the specified size. Many times, smaller fittings are used because they are in stock, but such fittings reduce airflow to the unit, resulting in reduced static draw.
- A vacuum should have the lowest air consumption unit that accomplishes the job. Most vacuum manufacturers carry specially designed vacuums for the powder industry.

- A vacuum with a high-efficiency filter media will prevent powder bypass.
- A vacuum should have a noise level below OSHA standards.
- The vacuum should have a static conductive hose and vacuum tool.

CLEAN ROOMS

Clean rooms are one of the best ways to help eliminate contamination entering the powder application area from outside sources. Clean rooms make painting a quality endeavor by promoting a cleaner environment for operators and for applying powder coating.

Clean rooms can be made from many materials, including regular building materials such as steel framing and sheet rock. However, many companies prefer modular-style enclosures made from panels that are easily snapped together. These panels are movable and can be relocated, expandable, and provide maximum flexibility and fast installation. Any panel can be exchanged with similar-size panels that are in this totally nonprogressive system.

Panel core choices include:

- phenolic resin-impregnated honeycomb;
- polystyrene;
- isocyanurate; and
- hollow-cavity stud core.

Most manufacturers build these panels so that joining panels are flush to create a dust-free environment. Painting the panels gloss white adds light and makes walls easy to clean during maintenance. Air locks can be installed within the clean room system. Doors and windows for application viewing can be installed anywhere. These partition-type clean rooms are considered equipment, or temporary, and not improvements to real property or permanent materials. Distinguishing between the two is important for depreciation and tax purposes.

Performance Testing

Many tests and standards assess the performance properties of powder coatings. Some tests are administered only once and others are administered at periodic intervals. This chapter provides an overview of common industry tests and standards.

Powder performance depends on a variety of factors, especially the quality and formulation of the materials, the type and condition of the equipment applying the powder, and the skill of the equipment operator applying it. Most powder-coating failures can be traced to an inadequate knowledge of processes, improperly maintained equipment, or inadequate substrate pretreatment. Each factor must be carefully monitored in any powder-coating process. Powder manufacturers can provide information on specific tests and on a testing schedule. End users and powder manufacturers need to agree beforehand what constitutes the failure or success of a particular coating.

Employees responsible for testing should be thoroughly trained and given written testing procedures so tests can be performed consistently. Accurate record-keeping of performance tests and results allows those responsible for quality control to track and evaluate whether the process is working smoothly. It can also reveal whether a trend is emerging or if some aspect of the process has begun to fail. Testing should be performed on properly pretreated and coated substrates. If problems seem to be occurring

in the pretreatment system itself, pretreated panels—available from a few manufacturers—can be purchased.

ASTM STANDARDS

The American Society for Testing and Materials (ASTM), founded in 1898, was established to develop standards on the characteristics and performance of materials, products, systems, and services, and for the promotion of related knowledge. ASTM standards contain objective-testing methods specifically designed to provide uniform, consistent testing data. The use of ASTM standards is purely voluntary. Industry professionals recognize that ASTM standards may be too restrictive or not restrictive enough for certain applications in certain regions of the world.

Performance Properties and Typical Tests

Gloss

In general, *gloss* means the property of a surface to reflect directed light. Gloss is typically evaluated by looking at a surface, and thus the evaluation is influenced by:

- physical factors (surface characteristics),
- physiological factors (of the human eye), and
- psychological factors (of the observer).

Objectively quantifying gloss is difficult because of the subjective nature of the physiological and psychological factors involved in the evaluation. Nevertheless, since gloss is an important quality feature, manufacturers have sought accurate methods to measure it.

Gloss meters, which are standardized according to the ASTM, the Deutsche Institute für Normung (DIN), and the International Organization for Standardization (ISO), make quantifying gloss possible. Figure 14-1 shows a typical gloss meter.

The gloss meter measures the reflective behavior of a surface and provides a gloss value that is relative to a black gloss standard. Gloss standards specify the source and receptor angle of the

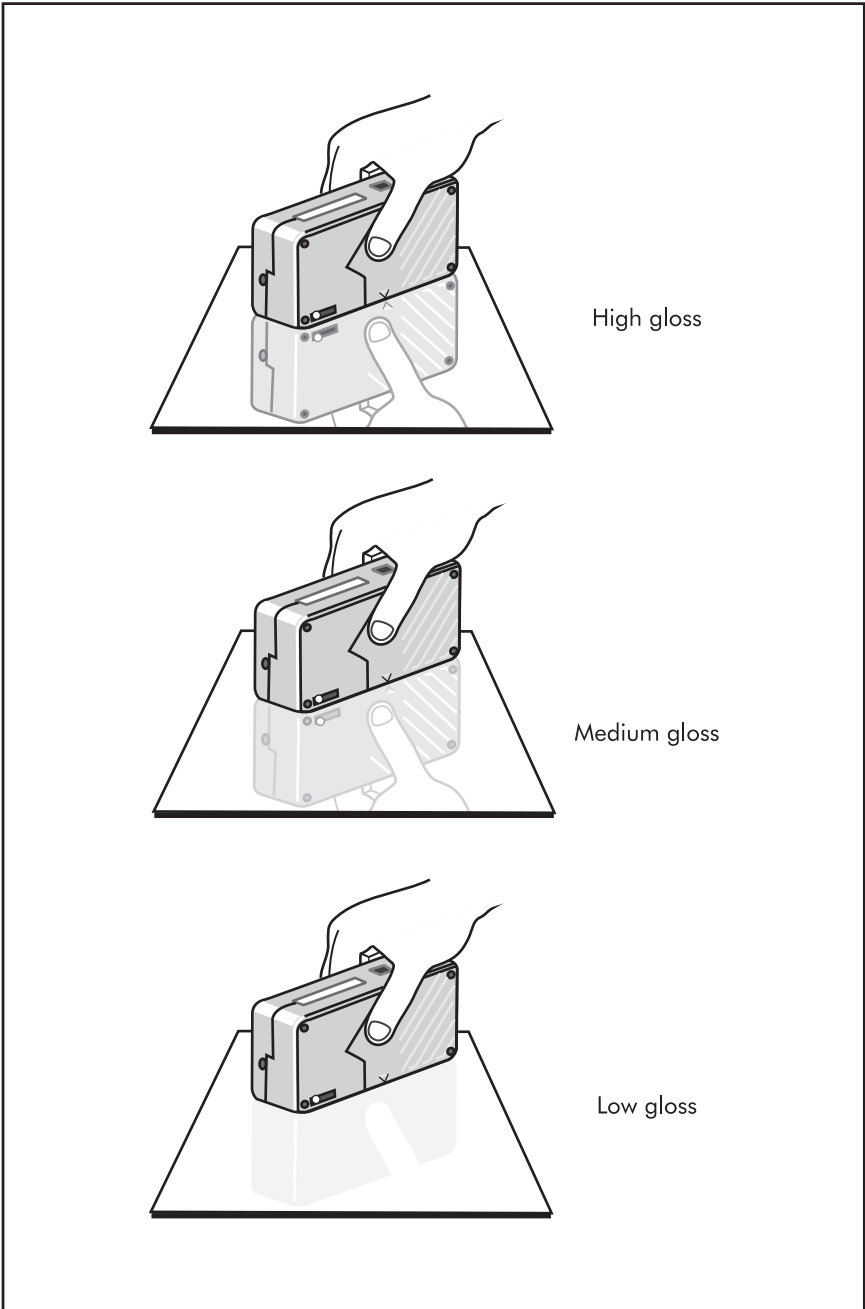


Figure 14-1. Measuring with a typical gloss meter. (Courtesy Byk Gardner)

meter, the source image, and the receptor aperture. They also specify conditions for achieving optimal measurements. The surface must be:

- flat,
- structure free, and
- uniform in color and brightness.

Meeting these standards in the laboratory is not difficult. In the production environment, however, difficulties arise if the surface bends, has structures, dirt, scratches, or streaks, which may be present during the testing of used, weathered surfaces.

Corrosion

Corrosion occurs as a result of substrate exposure to chemicals or moisture. Powder coats provide corrosion protection, depending on the formulation of the powder, how carefully it is applied, and the proper pretreatment of the substrate. Powder coats can be formulated to provide protection from a range of chemicals (such as those found in common household cleaners, oils, gas, brake fluid, antifreeze, oven cleaners, and household food stuffs) and specific chemicals (such as bleach, acetone, isopropyl alcohol, and methyl ethyl ketone). Pinholing of the coating surface, possibly occurring during the curing phase (if the substrate is not properly pretreated), can lead to a failure of the coating's resistance to corrosion if the pinholes reach the surface of the substrate.

Testing for resistance to humidity. ASTM D 2247-68 specifies the standards for testing the resistance of coated metal specimens to humidity. It also details the conditions for maintaining a controlled atmosphere at 100% relative humidity.

Specimens may be scribed or unscribed prior to being tested. (*Scribing* is cutting through the coated surface to the substrate below. Either a sharp cutting blade or a tool with uniformly spaced cutting edges may be used.) The ASTM D 2247-68 test for humidity is far less corrosive than the ASTM B-117-97 salt-spray test, as no salt is introduced to the substrate. What constitutes failure should be agreed upon between the purchaser and the seller. Ratings can be applied as cited in ASTM 1654.92. The standard states

methods for evaluation and rates the degree of failure with respect to the corrosion of a previously coated specimen. The rating method is a numerical scale ranging from 0–10 (or complete failure to no failure). ASTM D-1654-92 does not state what is passing or failure. The test employs a single vertical scribe, unless a different method is agreed upon between the manufacturer and the user. Table 14-1 rates failure at the scribe. Table 14-2 rates the unscribed areas. Evaluation of the scribed specimens includes:

- air blow off (80 psi [552 kPa]), and
- scraping.

Salt-spray and ultraviolet-light testing (ASTM B-117-97). ASTM B-117-97 sets standards for testing resistance to salt spray, fog, and UV light. This standard specifies the conditions and parameters of the equipment, as well as the testing procedures.

Parameters for salt-spray testing are shown in Table 14-3. Figure 14-2 and 14-3 show typical salt-spray testing equipment. The

Table 14-1. Rating of failure at the scribe

Representative Mean Creepage from Scribe in.* (mm)	Rating Number
0 (over 0)	10
0–1/64 (over 0–0.5)	9
1/64–1/32 (over 0.5–1.0)	8
1/32–1/16 (over 1.0–2.0)	7
1/16–1/8 (over 2.0–3.0)	6
1/8–3/16 (over 3.0–5.0)	5
3/16–1/4 (over 5.0–7.0)	4
1/4–3/8 (over 7.0–10.0)	3
3/8–1/2 (over 10.0–13.0)	2
1/2–5/8 (over 13.0–16.0)	1
5/8 or more (16.0 or more)	0
* Approximate	

Table 14-2. Rating of unscribed areas

Area Failed	Rating Number
No failure	10
0–1	9
2–3	8
4–6	7
7–10	6
11–20	5
21–30	4
31–40	3
41–55	2
56–75	1
Over 75	0

Table 14-3. Parameters for salt-spray testing

	Cabinet 1	Cabinet 2
Angle	15°	30°
Salt concentration	4%	6%
pH	6.5	7.2
Air pressure	12 psi (83 kPa)	18 psi (124 kPa)
Collection rate	1.0	2.0
Temperature	92° F (33° C)	97° F (36° C)
Specific gravity	1.0255	1.0400

standard does not specify what constitutes success or failure of a subjected part or panel; this should be agreed upon between the powder manufacturer and end user.

The UV-accelerated weathering tester reproduces the damage caused by sunlight, rain, and dew by exposing the materials to alternating cycles of light and moisture at controlled, elevated temperatures. The tester simulates dew and rain by condensing humidity and water sprays. It simulates the effect of sunlight by employing fluorescent UV lamps. To simulate corrosion resulting

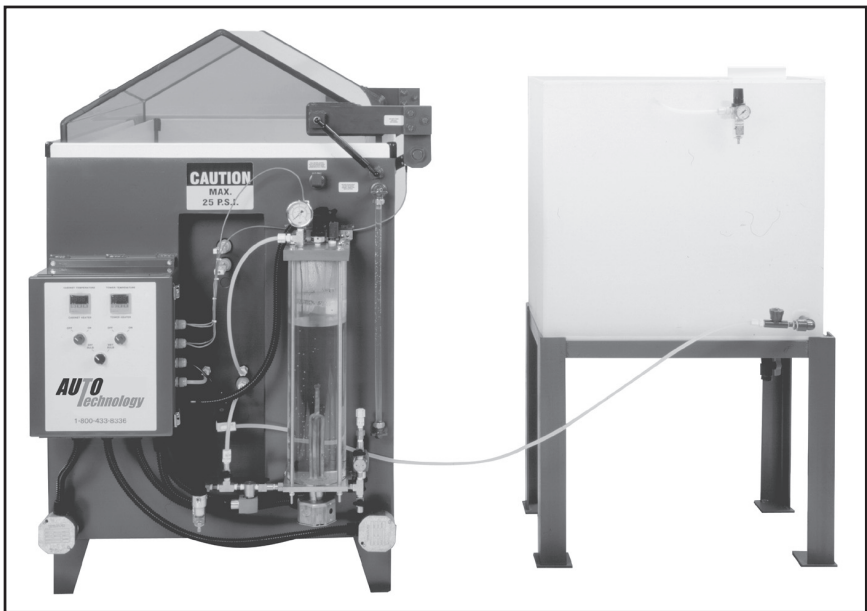


Figure 14-2. Salt-spray cabinet. (Courtesy Auto Technology)



Figure 14-3. Salt-spray, cyclic chamber. (Courtesy Auto Technology)

from exposure to sunlight, parts need be subjected only to the short UV wave, not the entire spectrum of sunlight. Although UV light represents only about 5% of sunlight, it is responsible for most of the outdoor photochemical damage to durable materials. Exposure conditions can be varied to simulate various end-use environments.

In a few days or weeks, the UV tester reproduces the damage caused by months or years of outdoor exposure. Damage produced by UV light includes changes in color, loss of gloss, chalking, cracking, hazing, embrittlement, and loss of strength. UV test data can aid in the selection of new materials, improvement of existing materials, or evaluation of changes in formulations.

Abrasion Resistance

An abrasion is any type of scratch resulting from an item being dragged across the surface of a coated substrate. Powder coatings generally provide outstanding abrasion resistance. Powder manufacturers typically provide specification worksheets outlining the abrasion resistance of specific powder formulations.

An abrasion is tested a number of ways, with the Taber Abrasion Test being the industry leader. This test method describes a procedure for determining the amount of image abraded from the surface. It is an industry standard used to test the wear and durability of ceramics, plastics, textiles, metals, leather, rubber, flooring, and painted and lacquered electroplated surfaces.

Pencil hardness test (ASTM D 3363-74). A variety of tests measure the ability of a coating to resist surface scarring or marking. Such tests include nickel rub, fingernail, and pencil hardness tests.

The pencil test is the most widely used test to determine hardness. This test is subjective because different people apply different pressures to the pencil as they are administering the test. The sharpness of the pencil tip may also affect the results, and pencil hardness may vary from manufacturer to manufacturer, complicating matters even further. Pencil lead hardness is rated on the following scale: (softest) 6B 5B 4B 3B 2B 1B HB F H 2H 3H 4H 5H 6H 7H 8H 9H (hardest).

The pencil hardness test specifies applying the pencil at a 45° angle. Begin the test using the hardest pencil lead and work toward the softest. The test is complete when the pencil does not gouge or scratch the film. Note that undercured coatings can be scratched with a lower value of pencil hardness than properly cured coatings.

Electrical Insulation

Powder coatings generally are good electrical insulators because powder conforms to the contours of the electrical part and permanently bonds to the part's surface to become an integral insulation that is void-free and of low bulk. (Powder coatings are usually low bulk as there is a limited amount of powder that can be practically applied to a part without changing the part's cosmetic look and the coating specification.) Typical applications where this property is important are automotive alternators, electric motors, and switchgears.

Heat Resistance

Most powder coats cannot be subjected to high temperatures without degrading. Degradation resulting from exposure to heat ranges from a slight yellowing of the coating to blistering and peeling. Some new powders withstand temperatures as high as 700–800° F (371–427° C), without degradation. Typical applications for these new powders are barbecue grills and outdoor cookware. These coatings are not suitable, however, for such applications as exhaust manifolds, which can produce temperatures exceeding 1,300° F (704° C).

Impact Resistance

Impact resistance measures the coating's ability to withstand a direct or indirect blow to the surface. Many companies provide impact-testing equipment. Generally, a metallic panel is pretreated and topcoated with the proposed system. The panel is cured, cooled,

and placed into the bottom of a ram-type piston. The ram head is dropped from a specified point and hits the surface of the panel. The test is repeated using increasingly more height on the ram until failure occurs, that is, the topcoat cracks or chips. Figure 14-4 shows a typical UV-light cabinet. Figure 14-5(a) shows a failed coating and Figure 14-5(b) shows a coating that successfully resisted impact.

The impact tester shown in Figure 14-6 has gained wide acceptance for testing the impact resistance of many types of coatings, from paints and varnishes to tough-plated plastic or powder-coated panels. It also is used for establishing quality-control standards for resistance to surface damage and penetration of many construction materials. These standards describe a method for evaluating the impact resistance of a coating to cracking or peeling from a substrate when it is subjected to a deformation caused by a falling weight, dropped under a standard condition.

The testing apparatus that was shown in Figure 14-6 consists of a guide-tube support situated on a solid base. The guide tube has a slot to direct a cylindrical weight when it slides up or down,



Figure 14-4. Typical UV light cabinet. (Courtesy QUV)

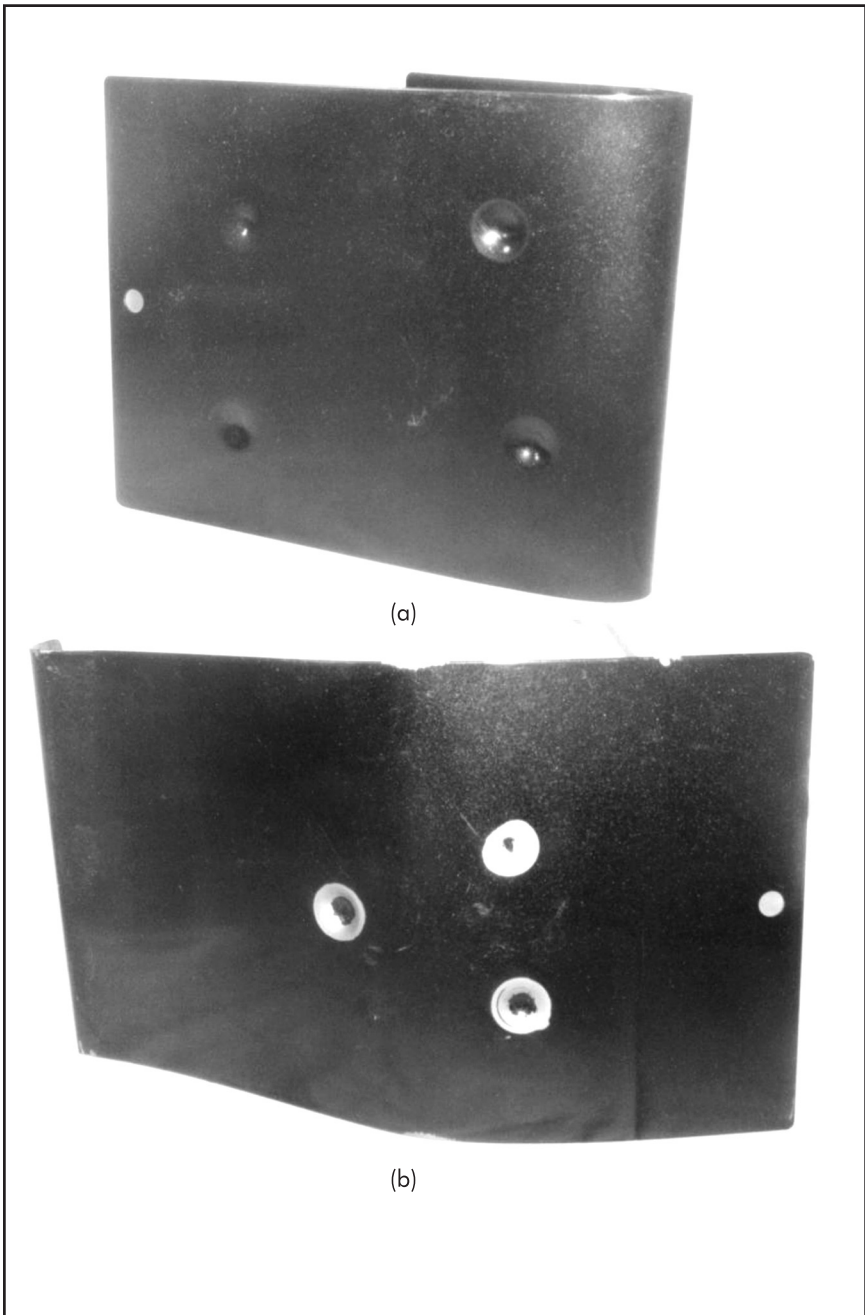


Figure 14-5. Results of impact test.

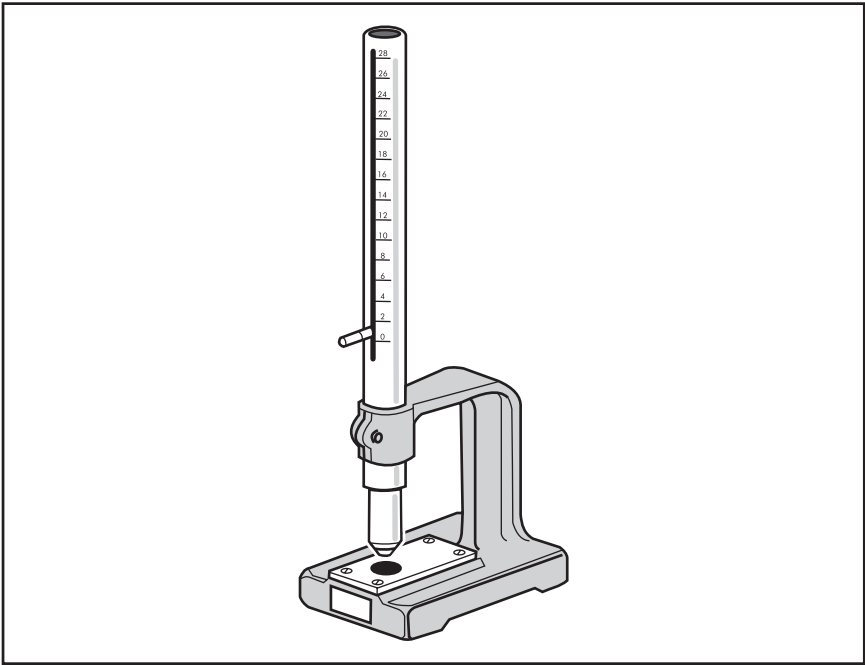


Figure 14-6. Impact tester.

enabling the user to easily return the weight to the same dropping position. The cylinder is graduated along the slot to facilitate reading. The base of the instrument includes a die support. The weights have steel balls built into their striking surfaces to provide different geometrical-type configurations. The ball diameter must fit that of the die to prevent the test samples from being sheared at the inner rim of the die. Generally, the apparatus lifts and then drops a 2 lb (0.9 g) ball. The falling weight can be varied by adding or removing weights. To limit the indentation depth of the falling weight, distance rings of different thicknesses can be fitted. For testing, place the coated side of the panel facing up or down, depending on the application, such as intrusion or extrusion.

The test can be performed as a pass/fail operation using a defined amount of impact energy (falling weight $\times$ height), or by increasing the impact energy until failure occurs. For this purpose, raise the weight to a height where no failure is known to

occur. Keep repeating this procedure, raising the weight each time until failure occurs. The test should be carried out in at least four different places on the test panel, not less than 1.6 in. (4 cm) from each other.

ASTM D 2794-84 tests the resistance to rapid deformation. It is used for parts that are subjected to impact or dents. The typical testing device is shown in Figure 14-6. This specification is primarily for materials that are subject to impact or dents in the final product.

Impact resistance is primarily a function of the paint. Failure of impact can be due to:

- paint quality,
- curing of paint, and/or
- improper pretreatment.

Testing for Other Properties

Proper curing (MEK cure test). The methyl ethyl ketone (MEK) cure test determines whether a topcoat is fully cured (see Figure 14-7). To administer the test, generously wet a stiff, wood-shafted swab in a MEK bottle (note that swabs with plastic or paper shafts deteriorate rapidly, potentially affecting the outcome). With the thoroughly soaked swab, double rub a small area, about 1 in.² (25.4 mm²) of the coated part surface approximately 50 times (each double-rub consists of one back-and-forth motion, as if erasing a pencil mark). If the powder coating is properly cured, little surface color transfers to the tip of the swab. (Note that many polyester powders leave more color on the swab than other powder chemistries.) The swab is then compared to one tested on a fully cured panel supplied by the manufacturer. (Note that different powder chemistries have differing degrees of MEK resistance.)

Crosshatch test for topcoat adhesion (ASTM D 3359-83). The crosshatch test determines whether pretreatment is providing adequate adhesion for the topcoat. The test presumes the cure has taken place and is approved. It is administered by cutting several crosshatches in the film, about 1/8 in. (3.2 mm) apart, using a utility knife or industry-approved cutters, as shown in Figure 14-8. A pressure-sensitive adhesive tape is then applied

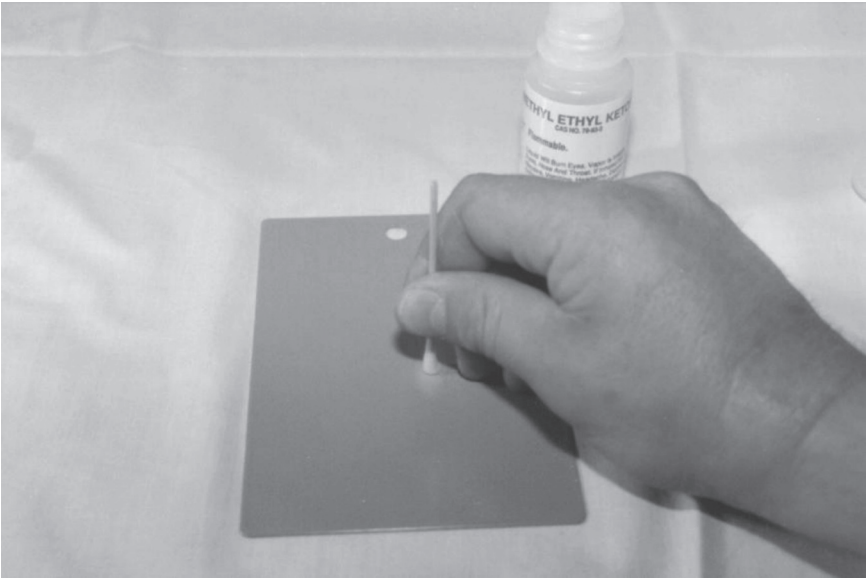


Figure 14-7. MEK cure test.

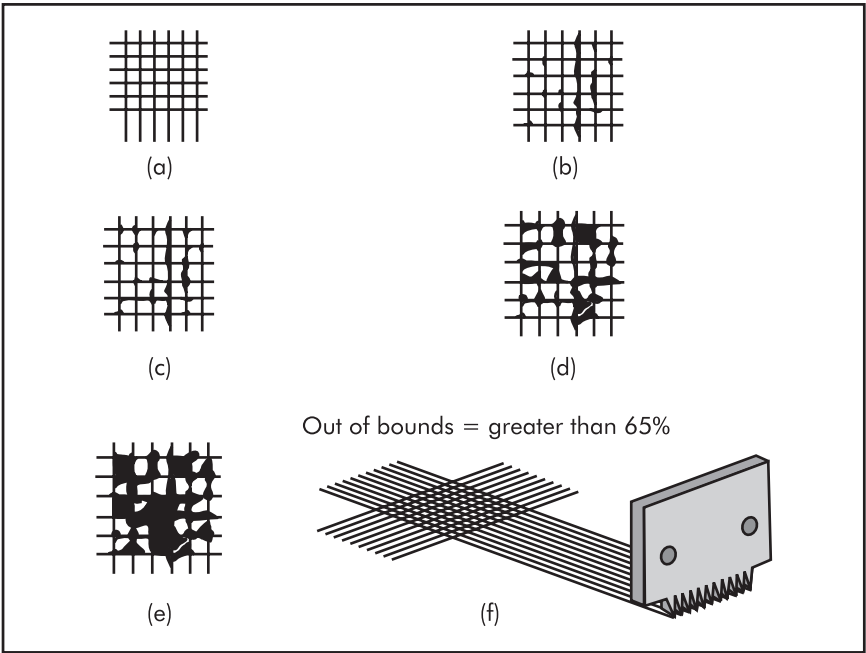


Figure 14-8. Crosshatch test.

over the crosshatches and pulled off rapidly. The adhesion of the coating is rated on its ability to resist being removed from the substrate. Different powder chemistries show different results. Partial curing shows up in this test because the powder may have only begun to cross-link and is therefore brittle. A mandrel bending of the test panel can sometimes indicate pretreatment failure. The rating system is:

- 5A = no peeling or removal;
- 4A = trace peeling or removal along incisions;
- 3A = jagged removal along incisions up to 1/16 in. (1.6 mm);
- A = jagged removal along most of incisions up to 0.5 in. (12.7 mm) on either side;
- 1A = removal from most of the area of the X under the tape;
- and
- 0A = removal beyond the area of the X.

Method B of this test is performed on thicker films if wider-spaced cuts are employed. This method employs a lattice pattern for up to 2 mils [0.05 mm] thick, 11 cuts, 0.04 in. (1 mm) apart; (2–5 mils [0.05–0.13 mm] thick, 6 cuts, 0.08 in. (2 mm) apart).

Film-thickness test. The film-thickness test measures whether the proper amount of powder coat is being applied. Figures 14-9, 14-10, and 14-11 illustrate commonly used gages for

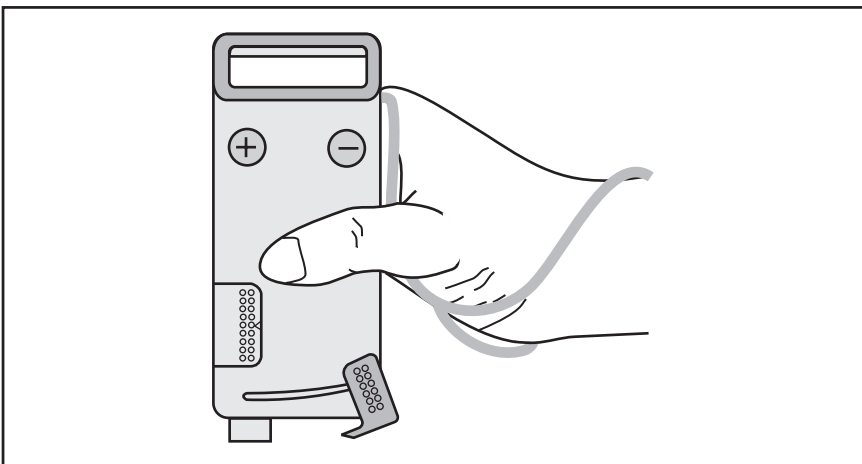


Figure 14-9. Hand-held gage. (Courtesy Positester)

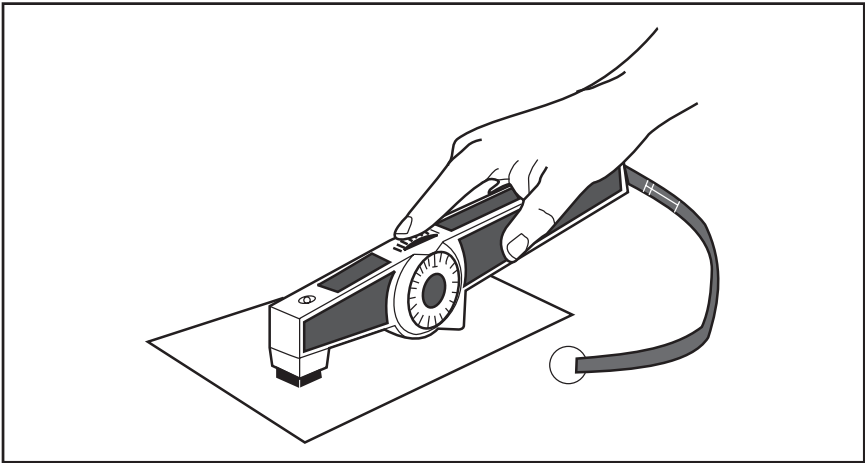


Figure 14-10. Banana-style mil thickness gage. (Courtesy Elcometer, Inc.)

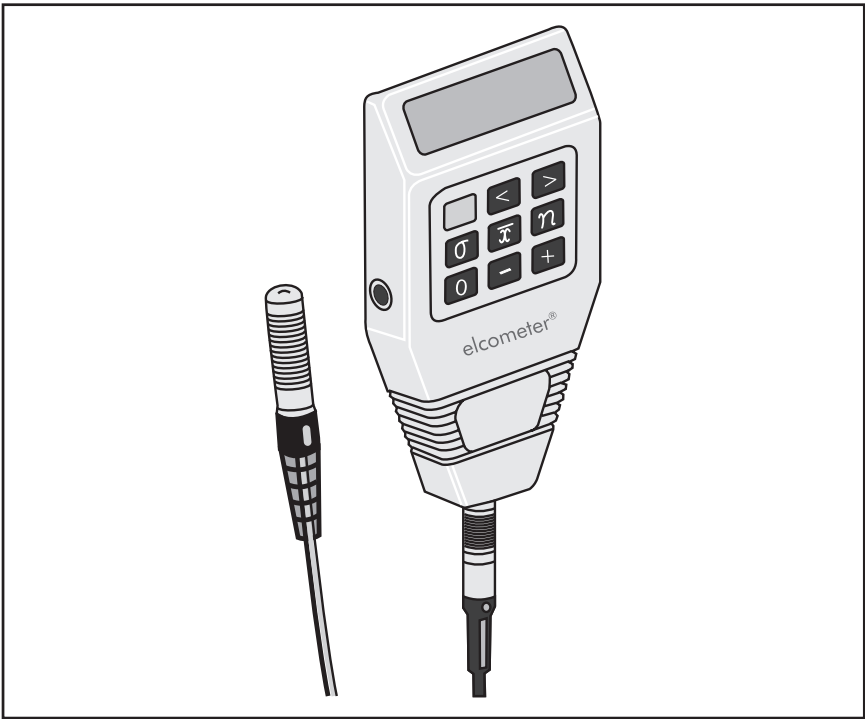


Figure 14-11. Probe-style mil thickness gage. (Courtesy Elcometer, Inc.)

measuring film thickness. Figure 14-9 shows a gage that should be held upright and perpendicular. Figure 14-10 shows a magnetic banana-style gage. Figure 14-11 shows a gage with a separate probe. The measurement of the coating thickness is dependent on magnetic attraction. The attractive force is related to the distance between a permanent magnet and a steel substrate. This distance represents the thickness of the coating to be measured. The magnet is lifted from the surface by means of a spring connected to the magnet arm. The spring is tensioned by means of the thumb wheel and the coating thickness is shown directly on the scale.

Before taking a measurement, calibrate the gage by measuring a known standard or a standard plastic shim that is placed on the uncoated surface of the substrate. Coated thickness standards and plastic shims are available in various thicknesses for calibrating gages on ferrous and nonferrous substrates. Both coating thickness standards and plastic shims are based on National Institute of Standards and Technology (NIST) standards. Always verify that the gage reads zero on an uncoated surface, or that it reads a known thickness accurately, especially if the substrate changes in shape, diameter, composition, or surface roughness, or when measuring on a different location of a part.

To use a calibrating gage such as the one shown in Figure 14-12, place the probe of the gage flat on the surface to be measured. Some gages beep to let the user know a measurement has been taken. Take a number of measurements and then average them. Do not take any measurements when parts are hot, since probe tips used on the gages will melt.

A fully electric gage uses the magnetic principle to measure nonconductive coatings on ferrous substrates; the eddy current principle is used to measure nonconductive coatings on nonferrous substrates.

Paint stretching (ASTM D-522). ASTM D-522 measures the stretching capabilities of paint. This is the standard test method for measuring the elongation of attached organic coatings with a conical mandrel apparatus. The lack of quality of the coating, improper pretreatment, and improper curing can cause failure of the conical mandrel.



Figure 14-12. Calibrating gage. (Courtesy Elcometer, Inc.)

CHEMICAL RESISTANCE

Each type of powder coating provides some degree of chemical protection to the topcoat and substrate. Chemicals are not limited to any one specific group. The powder can be formulated to help protect the surface against a specific chemical. Household cleaners, oils, and gas are among the primary types of specific chemicals. Other chemicals that industry tests against are chlorine, anti-freeze, acid, isopropyl alcohol, brake fluid, acetone, MEK, oven cleaner, and household food stuffs.

Troubleshooting

This section will cover troubleshooting for:

- off-color parts;
- off gloss;
- poor adhesion of powder to substrate;
- poor adhesion to powder coating;
- transfer efficiency;
- fluidization;
- clumping, blocking, or sintering;
- unacceptable surface appearance;
- protrusions;
- craters, pinholes, and fisheyes; and
- choosing coating.

Table 15-1 gives tips on troubleshooting the overall electrostatic operation. Table 15-2 gives guidelines for troubleshooting finish-cured film.

OFF COLOR

If a part is off color, the operator must assume there is a problem and he or she needs to decide whether it is due to changes in the application parameters or if the product is truly different.

A change in curing conditions can bring about increased yellowness of the binder or, if the temperature is lower than usual, bring a shift to the blue side. The mass of the part has a direct

Table 15-1. Troubleshooting the overall electrostatic-coating operation

Trouble	Possible Causes	Possible Solutions
1. Poor charging—inadequate powder build or wrap on part	1. High-voltage source not providing enough kV at charging electrode or grid 2. Poor ground 3. Powder delivery (feed) is too high 4. Excessive moisture in the powder-booth air 5. Powder too fine	1. Check that high-voltage source is on (systematically check electrical continuity from voltage source to electrode [grid] including cable, resistors, and fuses); replace missing or broken electrode; and clean electrode (grid) insulated by powder build or impact fusion. 2. Check ground from conveyor rail (or rub bar when used) through hanger to part. All contact areas must be free of powder build-up, heavy grease, and other insulating material. 3. Turn down powder feed until all material passing through the charging corona (field) is adequately charged. 4. Moisture in humid air will tend to dissipate humidity in the powder spray area. 5. Too much reclaim added to virgin powder; and virgin powder pulverized too fine by manufacturer.

Table 15-1. (continued)

Trouble	Possible Causes	Possible Solutions
2. Poor penetration—powder will not coat Faraday Cage areas (holes, grooves, channels, inside corners, and recesses).	6. Powder type or formula	6. Some resin types charge better than others and some formulas are designed for thin film application.
	7. Powder delivery air too high; powder blowing by part	7. Turn down air setting or move gun position farther away from part.
	1. Powder delivery too low	1. Turn up powder delivery air setting; use gun barrel extension.
	2. Poor ground	2. Check ground (see powder delivery).
	3. Powder spray pattern too wide	3. Select smaller deflector or use suitable slotted barrel and cover.
	4. Voltage too high	4. Turn voltage setting down so powder builds on part edges and leading surfaces do not repel powder from corners.
	5. Powder delivery velocity too high	5. Turn air settings down so powder/air stream does not blow powder out of the corners.

Table 15-1. (continued)

Trouble	Possible Causes	Possible Solutions
	6. Poor gun placement	6. Adjust gun position so the powder cloud has a direct path to the recess area.
	7. Powder too fine	7. Too much reclaim added to the virgin powder; and virgin powder pulverized too fine by the manufacturer.
3. Back-charging powder layers are repelled from part in some spots	1. Voltage too high	1. Turn voltage setting down.
	2. Gun positioned too close to the part	2. Move gun placement away from the part.
	3. Poor ground	3. Check ground (see powder delivery).
	4. Powder too fine	4. Too much reclaim added to the virgin powder; and virgin powder pulverized too fine by the manufacturer.
4. Powder picks up a random charge through fluid path	1. Powder-booth air too dry	1. Adjust powder-spray area humidity.
	2. Poor delivery and reclaim equipment ground	2. Provide ground for all equipment.

Table 15-1. (continued)

Trouble	Possible Cause	Possible Solutions
5. Powder feed spurring or slugging—interrupted powder feed	1. Insufficient air pressure or volume 2. Hoses kinked, flattened, or too long 3. Hoses, pump venturis, or guns clogged with powder	1. Check air supply. Air supply to equipment should be sufficient. Enough air volume should be available when other equipment, such as the reverse air cleaner in reclaim housing, pulses so that air pressure to powder feed does not drop. 2. Check powder-feed hoses. 3. Clean hoses, venturis, and guns; check air supply for moisture that causes powder compaction; check powder's free-flowing properties; check spray-booth air humidity; and check powder supply for contamination.
6. Poor spray pattern—not a symmetrical powder cloud (not applicable when using specialized deflectors)	1. Worn electrostatic-gun parts	1. Replace worn feed tubes, orifices, deflectors, and covers. 2. Clean gun parts as needed. 3. Check air supply. Increase air for powder feed. 4. Clean the hoses, venturis, and guns.

Table 15-2. Troubleshooting finish-cured film

Trouble	Possible Cause	Possible Solutions
1. Poor impact resistance/poor flexibility	1. Under-cured	1. Increase oven temperature or increase dwell time in the oven.
	2. Poor cleaning or pretreatment	2. Check pretreatment equipment and chemicals.
	3. Film thickness too high	3. Reduce film thickness by adjusting the application equipment.
	4. Change in substrate thickness or type	4. Check substrate with supplier.
	5. Powder resin type or formula	5. Check with the powder manufacturer.
2. Poor adhesion	1. Poor cleaning or pretreatment	1. Check pretreatment equipment and chemicals.
	2. Change in substrate	2. Check substrate with supplier.
	3. Under-cured	3. Increase oven temperature or increase dwell time in the oven.
	4. Powder resin type or formula	4. Check with the powder manufacturer.
3. Poor corrosion resistance	1. Poor cleaning or pretreatment	1. Check pretreatment equipment and chemicals.
	2. Under-cured	2. Increase oven temperature or increase dwell time in the oven.

Table 15-2. (continued)

Trouble	Possible Cause	Possible Solutions
4. Poor chemical resistance	1. Under-cured	1. Increase oven temperature or increase dwell time in the oven.
	2. Powder resin type or formula	2. Check with the powder manufacturer.
5. Poor pencil hardness/abrasion resistance	1. Under-cured	1. Increase oven temperature or increase dwell time in the oven.
	2. Powder resin type or formula	2. Check with powder manufacturer.
6. Poor surface flow/ too much orange peel	1. Film thickness too thin	1. Increase film thickness by adjusting the application equipment.
	2. Heat-up rate too slow	2. Increase oven temperature or increase dwell time in the oven.
	3. Powder resin type or formula	3. Check with powder manufacturer.
7. Gloss too low for high-gloss powder	1. Incompatible powder contamination	1. Clean application equipment before changing powders.
	2. Micro-pinholing from gassing	2. Check the substrate for porosity; check the substrate for moisture; check the powder for moisture from reclaim or compressed air; or check the film thickness, coating may be too thick.
	3. Powder resin type or formula	3. Check with powder manufacturer.

Table 15-2. (continued)

Trouble	Possible Cause	Possible Solutions
8. Gloss too high for type of powder	- Under-cured - Powder formula	- Increase oven temperature or increase dwell time in the oven. - Check with powder manufacturer.
9. Contamination in powder	- See Table 5-6 - Virgin powder contaminated	- Replace sieve or repair as necessary; clean the conveyor regularly before entering the powder-spray booth; strip the hangers as needed; check cleaning and pretreatment equipment and ensure proper part drainage before entering the spray booth; isolate the spray booth area; preferably enclose in a room with filtered, humidity-controlled air. - Check with powder manufacturer.
10. Inconsistent film thickness	- Guns positioned wrong - Reciprocators not matched to the line speed - Airflow in booth disturbing spray pattern - Defective spray equipment	- Check and reposition guns so spray patterns overlap slightly. - Adjust the line speed or adjust the reciprocator stroke. - Consult equipment supplier. - Go through application section checklist.

Table 15-2. (continued)

Trouble	Possible Cause	Possible Solutions
11. Off color	1. Improper oven exhaust 2. Bake time too long 3. Oven temperature too high 4. Variation of film thickness 5. Powder formulation	1. Check exhaust-vent fan(s). 2. Adjust line speed. 3. Lower oven temperature. 4. See surface appearance section of this chapter. 5. Check with powder manufacturer.
12. Pinholing and gassing through coating surface	1. See surface appearance section of this chapter.	1. Check storage facilities; powder should be stocked at room temperature in closed packing (maximum humidity 75%).
13. Pull-away or tearing/coating film shrinks leaving bare substrate	1. Uncharged powder 2. Poor cleaning, metal preparation, or dry-off	1. See Table 15-1. 2. Check pretreatment equipment, dry-off oven, and part drainage.

bearing on the actual heat history of the coating. A heavy part will take a lot longer to reach a given temperature under the same conditions in an oven and typically yellow less. Figure 15-1 shows a flowchart for determining why the product is off color.

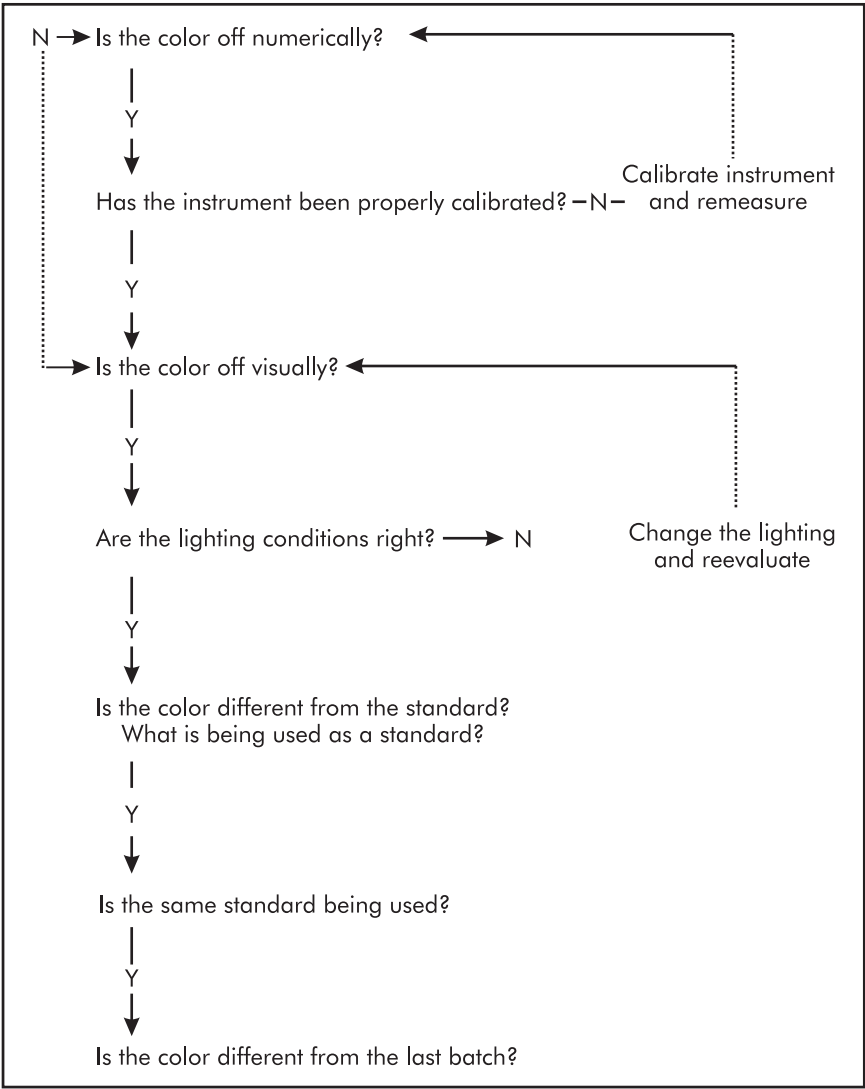


Figure 15-1. Flow chart for determining why a product is off color.

If there are many heavy parts in the oven at the same time, the oven's ability to heat up the coating will be greatly reduced, resulting in a different color than specified.

If an oven profile (DataPac[®]) was run recently, it will help determine if oven conditions are consistent. If the oven was calibrated and serviced recently, this helps rule out whether it is contributing to the problem. Gas ovens are known to bring about a yellowing of the coatings that they cure. A change in composition of the gas also can bring noticeable color changes. IP ovens generate very high temperatures and can easily over-bake coatings. A properly vented gas oven exposes the powder paint to considerably lower concentrations of combustion by-products than a poorly vented one, again influencing the degree of yellowing.

A lot of smoke escaping from an oven could indicate poorly maintained or designed equipment. If there have been line stops while coated parts are in the oven, some of the coating may be overexposed to heat, resulting in a different color and possibly other effects.

The perception of color often is dependent on the surface of the coating. If the gloss or texture change, there is usually a change in perceived color. Film thickness can influence color if substrate shows through the film. In the case of metallics, kV, powder-flow settings (air velocity), as well as the type of guns used for the powder application, greatly influence the color.

Some further questions that help to determine whether color changes relate to an application problem or a powder problem include:

- Have the parts been coated successfully before? This will help to determine if you are using the right product for the application.
- Has the operator experienced off-color parts before? If so, the operator should have an idea as to what the problem was in the past and how it was fixed.
- Does the operator have the ability to cure the product under controlled conditions such as a lab oven? If the color still comes out off, the likelihood is much greater that there is a powder problem.



OFF GLOSS

First, the operator needs to determine that a problem exists with product gloss. What gloss is the operator getting? What product gloss is he or she trying to use? Is it the right gloss for the product? What is being used for a standard? Figure 15-2 shows a simple flow chart for gloss assessment.

At this point, the operator needs to assume there is either an application or a powder problem. To do so, he or she should know at what mil thickness coating is taking place, and at what length of time and level of temperature the product is in the oven. With most powders, the resulting gloss is dependent on the cure schedule. Higher temperatures or excessive time lower the gloss.

If DataPac or some other program was run recently, this serves to ascertain if the product is cured according to recommendations and that the operator has control of the process.

If the oven was calibrated and serviced recently, this allows ascertaining that the process is under control.

A change in line speed or oven setting results in a different heat history and, therefore, different gloss levels. Other factors affecting gloss include the kind of oven, whether it was designed for liquid or powder, and the age of the oven. If gas ovens are not properly vented, it may result in reduced gloss levels.

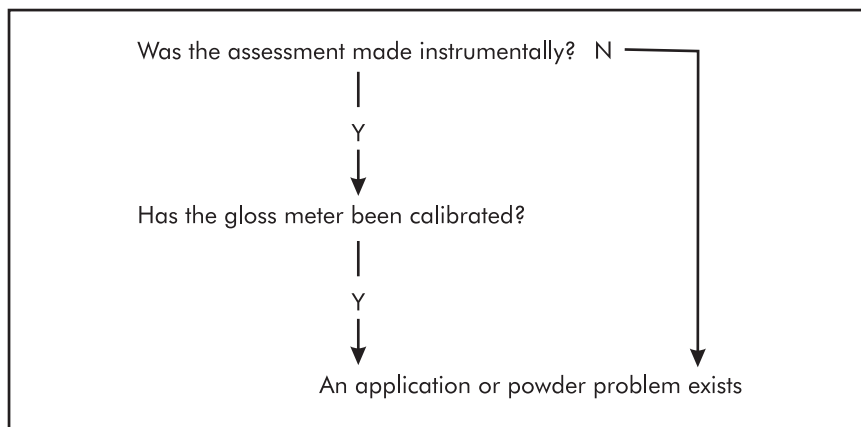


Figure 15-2. Flow chart for gloss assessment.

Different levels of gloss on different parts or different areas on the same heavy parts may indicate that the cure schedule may not be sufficient to produce the desired gloss. Parts with different thicknesses of material may produce different heat histories for the coatings that go over them.

Oven loading dictates how quickly parts reach their final temperatures and thereby influences development of gloss. If the oven is full of heavy parts, they may act like a heat sink and reduce the temperature in the oven significantly, thereby raising gloss levels.

A line stoppage would mean excessive heat exposure of the coating and typically lower gloss.

An operator should determine if there are other powders sprayed nearby or if the powder has been blended with any other ones. If there is cross contamination of other powder chemistries, this may result in a reduction in gloss. Also, blending different powders or even different lots might result in incompatibility and a reduction in gloss.

Further items that determine whether or not the powder is a likely cause include:

- Certain chemistries like low-gloss epoxies and low-gloss urethanes are very sensitive to curing conditions.
- If the powder is excessively old it may have undergone changes that affect the gloss of the coating.
- If the powder was exposed to too much heat, gloss development can be influenced.
- If the powder is lumpy, this indicates a storage problem or overexposure of the powder during shipping.

If the operator can spray the powder under controlled conditions, this allows him or her to verify whether there is a process problem or a powder problem. If the coating comes out high or low in gloss, there is a much greater likelihood of the powder being off. Off gloss would point to whether there is high probability the process is off or the powder is different from the last batch, lot, or box.

Other factors to consider are whether there have been any problems with the product before, and whether it can be cured and the gloss checked under controlled conditions.

POOR ADHESION TO THE SUBSTRATE

The operator first needs to determine whether poor adhesion results from a failure in adhesion of the cured film or if the powder is not sticking to the part. If the latter is the case, it is an application problem. The operator must make certain that he or she is seeing delaminating of the film and not simply describing a lack of flexibility/impact resistance as adhesion failure.

One problem that can cause adhesion failures is under-cure of the product. A methyl ethyl ketone (MEK) rub test or an equivalent test will rule out that scenario.

The oven should have been calibrated recently and an oven profile run to determine if the cure is adequate. The operator also should check adhesion on B-1000 or equivalent test panels.

Typically, adhesion failure is an issue of substrate and pretreatment related to what types of parts are being coated.

If the failures occur only in specific areas, powder can be ruled out as the cause. If the failure is general, it is most likely an issue of substrate and cleaning. A white residue may indicate the presence of phosphate salts and an incomplete rinse; a red residue may indicate rust; and gray residue some kind of smut or even excessive conversion coating, which also may prevent adhesion of the film.

Facts to know about the parts include:

1. Burned coating, or other organic material, may leave a carbon-rich residue that can prevent adhesion of the coating to the part.
2. A change in cutting or stamping oils may mean that the cleaning steps assumed to be sufficient are not anymore. Also, parts that have sat in any oils to prevent them from rusting may be very difficult to clean. Pretreatment itself is a pretty complex area and there are plenty of things that can go wrong.
3. When parts leave the final rinse, the water should break free and not leave discrete drops on the surface. If all inorganic soils are removed from the surface of the part, the water comes off in a sheet. Presence of drops indicates incomplete removal of the soil.
4. If the parts look mottled or streaky when they leave the drying oven, the surface the powder coats is not the same every-

where on the part, and hence adhesion failures may be expected.

5. If there is residue when a clean rag is wiped over parts as they leave the drying oven, this indicates residual soils or possibly excessive deposition of the conversion coating. Either one reduces the amount of adhesion of the powder to the substrate.

POOR ADHESION TO THE POWDER COATING (RECOATABILITY)

How poor adhesion to the powder coating manifests itself determines what possibilities outside of the powder coating are to be considered as possible causes of the failure.

If the operator sees bare metal, the failure is occurring between the substrate and the powder coating or the powder coating and the subsequent layers. Over certain coatings it may be difficult to get adhesion, for example, products that contain considerable quantities of waxes, textures, and highly cross-linked products. The operator must make certain he or she is using the right product for the application.

If the operator has successfully recoated, printed, or applied decals to a particular coating before, and there are now problems, there is a good likelihood that a change has occurred in the process to prevent adhesion to the coating.

Changes in the powder coating, like a different color or a lower gloss, can indicate excessive heat exposure of the coating. This can cause too much cross-linking or drive molecular weight products in the coating to the surface, thus preventing adhesion.

To determine that the product is being used according to specifications, the operator should check the oven settings and length of time the part is in the oven. A recent oven profile is also necessary.

TRANSFER EFFICIENCY

The operator should know the expected coverage, mil thickness, and ease of application. Is the operator using the same gun settings as in the past but seeing a smaller powder cloud? Or, is he

or she using the same gun settings and seeing the same powder cloud as in the past, but the powder is not sticking to the part? Table 15-3 gives tips on what to troubleshoot when the output of powder is insufficient to coat the parts.

The painter should recall when he or she first saw the problem—and what happened or what was done the last time it was seen. The operator should determine if this happens all the time on every part or just occasionally on a few parts. If it happens all of the time, it might imply a powder or process problem. If it happens occasionally, this points more to the process. If the problem is only seen occasionally, the painter should determine under what conditions.

A major clue is whether the coating problem happens everywhere on the parts or just in certain areas. (Faraday Cage areas may be difficult to coat.) If the problem is everywhere, it could be a powder or application issue.

If the part has been successfully coated before, the operator should determine if it was done with the particular lot of powder now in use and, if not, whether the previous powder came from a different manufacturer. He or she should study the shape, mass, and substrate of the parts being coated as well as whether it is difficult to coat Faraday areas. Heavy parts may ground better than small light parts and thus coat more easily. Complicated shapes with Faraday areas may take longer to coat or require reduced voltage or air pressure.

The same problem experienced with many different powders indicates a processing problem. When the problem is limited to one powder, it may still be a processing issue—or it could be a powder problem. If a company has successfully used a particular powder before on the same parts or any other parts, it is important to know whether grounding, gun settings, and/or the operator have changed. Poor grounding is a major cause of poor transfer efficiency and grounding should be checked with a mega-ohm meter. Dirty hooks cause poor transfer efficiency. Small/light parts may require hook cleaning after every use. Two to three times around the system is normally the maximum time before cleaning is required.

The operator needs to determine the answers to the following questions about gun settings:

Table 15-3. Troubleshooting: output of powder insufficient to coat parts

Trouble	Possible Causes	Possible Solutions
1. Poor fluidizing properties in the powder hopper	1. Pressure of fluidizing air too low 2. Fluidizing membrane is blocked 3. Humidity of compressed air too high 4. Humidity of the powder too high	1. Adjust (increase) pressure of fluidizing air. 2. Clean/replace the fluidizing membrane. 3. Install an air dryer with a corresponding oil micro filter. 4. Check storage facilities.
2. Blockage in venturis and hoses	1. Fusing of the powder in the venturi 2. Fusing of the powder in the hoses	1. Clean/replace the venturi; reduce the pressure to the venturi. 2. Clean the hose by bending and breaking up the fused powder. Replace the hose if necessary; install an air dryer with corresponding oil micro filter.
	3. Bad free-flowing properties of the powder	3. Contact powder supplier.

Table 15-3. (continued)

Trouble	Possible Causes	Possible Solutions
3. Blockage in the gun	1. Fusing in the gun or gun outlet	1. Clean the gun according to the instructions of the equipment supplier. When blocking occurs, frequently check humidity of compressed air and the free-flowing properties of the powder.
	2. Blockage caused by contamination of the powder with dust or other coarse materials	2. Clean the gun according to the instructions of the equipment supplier and determine the reason for the contamination. (Check powder pumps for possible impact fusion.) Impact fusion particles, which break off in the pump, could be transported to the spray gun and result in blockage.

- kV? Powder airflow? Low kVs equate to less charge, less transfer; high airflow equates to less charge, less transfer.
- Are the guns manual or automatic and what is the gun-to-part distance (6–8 in. [15–20 cm] is normal)? Too close can blow powder off the parts. Too far and the powder can drop away before it gets to the part.

Table 15-4 provides troubleshooting guidelines for poor or insufficient coverage problems.

The operator should know the line speed and racking density; too fast or too close together with difficult parts could result in missed areas. He or she should determine the virgin-to-reclaim powder ratio. Fine reclaim powder does not retain its charge and can be pulled away by airflow. As a rule, 50/50 mix is the maximum.

Other questions the operator should ask are:

- What is the humidity in the spray area? Recommended humidity is 45–65%. There is probably no upper limit, but some problems have been observed under desert conditions at 15–20% humidity. Dry air produces a positive charge.
- Does powder drift out of the booth? Are there fans or open doors near the booth? Excessive draft in the booth or airflow through the booth can pull powder away from the parts.
- How well is the powder fluidizing? Often, excessive post additives can make the powder fluidize well but charge poorly.

FLUIDIZATION

An operator who sees less powder coming through the guns might be inclined to recognize it as a fluidization problem when in reality the powder pumps are worn out or the hoses have excessive buildup. The operator should look for visual verification in the hopper that the hopper does not fluidize. Table 15-5 presents a troubleshooting guide for fluidized bed operations.

If the powder has been stored improperly, there is potential for the product to sinter and lose its ability to fluidize. One possible solution is a conditioning sieve—a device usually located near the reclaim module used to screen the reclaim material for dirt and fibers. The sieve also breaks up any powder that may have ag-

Table 15-4. Troubleshooting poor or insufficient coverage

Trouble	Possible Cause	Possible Solutions
1. Insufficient wrap around	1. Poor electrostatic charging of the powder	1. Adjust level of electrostatic kilo-voltage (increase). If not possible, check equipment and guns according to instructions of the supplier; check for broken electrodes on the spray gun. If found, replace electrodes; check for possible frictional transport through the powder hose. If evident, consult powder supplier for hose material recommendation.
	2. Insufficient ground	2. Check the ground contacts using a suitable resistance measuring device. Correct and insure sufficient earth to ground control.
	3. Output of powder too low	3. Increase the powder feed and/or powder flow.
	4. Using an unsuitable powder type	4. Contact powder supplier.
2. Poor penetration into corners, flanges, slots, etc.	1. Output of powder too low	1. Increase the powder feed and/or powder flow.
	2. Insufficient ground contact	2. Check the ground contacts and if necessary use a suitable measuring instrument.
	3. Powder cloud too wide	3. Narrow the powder cloud. If necessary, install a more suitable deflector or adjust air cone.

Table 15-4. (continued)

Trouble	Possible Cause	Possible Solutions
3. Poor adherence of powder to the part. Powder falls from the part easily.	1. Poor electrostatic charging of the powder	1. Adjust the level of electrostatic kilo-voltage. (Increase the voltage; if not possible, check the equipment and guns according to instructions of the equipment supplier.)
	2. Powder output too high or the pressure for the transport too high, which blows the powder from the object	2. Reduce the powder output and/or reduce the pressure of the transport air.
	3. Unsuitable particle size, distribution of the powder, or unsuitable powder type for the objects	3. Contact powder supplier.

Table 15-5. Troubleshooting fluidized bed operations

Trouble	Possible Causes	Possible Solutions
1. Dusting—powder blowing out of hopper	1. Air pressure too high 2. Powder too fine	1. Adjust air regulator to lower pressure to fluid bed. 2. Too much reclaim added to virgin powder; virgin powder pulverized too fine by manufacturer.
2. No air percolating through powder surface	1. Insufficient air pressure 2. Plugged membrane 3. Obstructed membrane 4. Compacted powder	1. Check air supply, increase air regulator pressure; check air line size to equipment. 2. Check membrane for plugged pores from dirty air supply. 3. Check bottom of bed for plastic, cardboard, or other large obstructions. 4. Manually loosen powder and fluidize well with clean, dry air.
3. Rat holing—air blowing large jet holes through the powder surface	1. Powder level too low 2. Packed or moist powder 3. Membrane obstructed 4. Plugged or broken membrane	1. Add powder until hopper is 2/3 full when fluidized. 2. Manually loosen powder and fluidize well with clean, dry air; check compressed air and booth air for high humidity. 3. Check bottom of bed for plastic, cardboard, or other large obstructions. 4. Check membrane for plugged pores from dirty air supply, cracks, or holes.
4. Stratification—powder separating into layers of fine and coarse particles	1. Powder level too high 2. Powder too fine	1. Remove powder until 2/3 full when fluidized. 2. Too much reclaim added to virgin powder.

glomerated, and therefore helps fluidization. A system may have design problems if it does not have such a device.

Typically, reclaim material is richer in fine particles, and might be so to the degree that the powder does not fluidize anymore. A virgin-to-reclaim ratio of 1:1 or even 1:2 certainly should raise a flag. Table 15-6 provides troubleshooting tips for collection and reclaim operations. If the parts lot has worked before and other products are fluidizing, then there is a much greater likelihood of a powder problem.

The fluidizing membrane is a porous plate that sits at the bottom of the hopper through which air is blown into the powder. If it becomes clogged, the air might not be able to generate the pressure to fluidize the powder correctly. If solvents are used to clean a membrane during a color change, there is a good chance of clogging the pores in the membrane.

The air dryer is essentially a refrigerator through which the air is passed after it passes through the compressor. The purpose of the air dryer is to remove any moisture from the air that might condense and clog the pores in the fluidizing membrane. If oil comes through the airlines, it may clog up the membrane. Condensation or build up of powder on the lenses of ultraviolet/infrared radiation (UV/IR) detectors may indicate moisture or oil being carried in the airlines. If the air is humid, moisture may condense around the powder particles and reduce fluidity.

Other questions to ask about fluidization include:

- Are powder bags or drums tied after opening? If the bags are not tied closed, there is a potential for moisture to enter into the bags and prevent the powder from fluidizing.
- When do problems occur? Powder sitting all weekend often needs extra help fluidizing at first.

CLUMPING, BLOCKING, OR SINTERING

Clumping, blocking, or sintering should be obvious; therefore, no verification of the problem should be necessary. Also, from a problem-solving point of view, either the powder already was lumpy

Table 15-6. Troubleshooting the collection and reclaim operation

Trouble	Possible Cause	Possible Solutions
1. Contamination in reclaim powder	1. Reclaim in-line sieve torn, missing, or inoperable 2. Powder or dirt falling in spray booth from conveyor or hangers 3. Contamination from parts entering the spray booth 4. Contamination from plant air circulated through spray booth	1. Replace sieve or repair as necessary. 2. Clean the conveyor regularly before entering the powder spray booth. Strip the hangers as needed. 3. Check cleaning and pretreatment equipment and ensure proper part drainage before entering the spray booth. 4. Isolate the spray booth area. Preferably, enclose in a room with filtered, humidity-controlled air.
2. Spray booth dusting/ inadequate airflow through booth	1. Bag or cartridge filters blinding 2. Final filters clogged 3. Too large of an open area in spray-booth housing 4. Powder delivery (feed) too high	1. Clean or replace bags or cartridge filters; check spray booth air humidity; check reverse air cleaning. 2. Check filter bags or cartridges for powder leakage. Repair or replace as needed. 3. Reduce open area. Increased opening reduces booth-air velocity. 4. Reduce the number of spraying guns or the amount of powder to each gun.

when it left the warehouse, or it degraded during transport or at the operator's facility.

The only item that needs clarification is whether the operator is dealing with a storage-related problem or if there is material in the powder box that should never have gotten in there. If other products experience the same problem, there is a good chance this is caused by the customer's storage conditions. Also, clumping can be caused if the temperature exceeds 75° F (24° C), the boxes are exposed to direct sunlight, or the product gets wet.

Ideally, quality checks on the product are performed at the time of receipt. If that was the case and the powder was okay at the time of receipt, then most likely, the powder deteriorated after shipping. Once in use, if the powder bags or drums are not tied closed after opening, there is a potential for moisture to enter the bags and prevent the powder from fluidizing.

UNACCEPTABLE SURFACE APPEARANCE

The frequency of colored specks could indicate whether there is a cleaning issue or a powder problem. If the specks are infrequent, it could be a cleaning issue. If the specks are the same color as was sprayed recently on that system, this also indicates a cleaning issue.

Uniform specks tend to indicate a powder problem; nonuniform, a system issue. If the colored specks are in a particular location on the part, this could indicate that something airborne is falling on the part. Questions to ask include:

- Have guns and booths been shared with other colors? If so, this could cause contamination.
- Is this powder virgin or reclaim? Reclaim powder may not fluidize properly.
- Was spraying successful with virgin powder? If so, then reclaim may be causing the problem.
- Are hoses and hoppers dedicated for particular colors? If not, there is risk of contamination. Table 15-7 gives troubleshooting tips for hoses and pumps.
- Does the operator thoroughly clean the gun hoses and spray booth after each color change?

Table 15-7. Troubleshooting hoses and pumps in a venturi operation

Trouble	Possible Cause	Possible Solutions
1. Plugged from impact fusion—hard build-up	1. Normal build-up 2. Air pressure too high 3. Moisture in air supply 4. Composition of powder feed hoses 5. Worn venturis and wear parts 6. Powder too fine 7. Powder type or formula	1. Clean or replace parts. 2. Turn down air settings on pumps and guns. 3. Check air supply for clean, dry air. 4. Check hoses. 5. Replace worn parts. 6. Too much reclaim added to virgin powder; virgin powder pulverized too fine by manufacturer. 7. Some resin types tend to have more impact fusion. Check with powder supplier.
2. Insufficient powder feed	1. Powder not fluidizing 2. Obstruction from contaminated powder supply 3. Kinked or flattened hoses 4. Worn pump venturis 5. Low air pressure	1. See fluidized bed section of this chapter. 2. Clean out venturis and hoses; check powder supply for contamination; sieve all reclaim before using. 3. Replace if permanently deformed; avoid sharp bends; use saddles for reciprocators. 4. Replace worn parts. 5. Check air supply. Adjust all settings to pumps and guns.

Blowing down the booth with an air hose could cause other colored particles or dust to drift. The best way to clean a booth is to first use a squeegee on the interior surface of the booth, after that a vacuum cleaner, then a damp rag to collect any residual amounts of powder. Only in the last instance, if absolutely necessary, should the operator use a blowgun to remove powder from any crevices where powder might still be hiding.

Other questions include:

- How and how often is equipment cleaned? This affects contamination.
- Are parts coated in more than one spray booth? This could result in contaminants.
- Could powder be migrating from booth to booth? Again, contamination risks rise.
- Are there any fans in the area that may be blowing powder or dust around? This can cause contamination.
- Are there open doors that may be causing excessive air exchange? This could affect both coating and contamination.
- Is the operator racking different colored parts in succession? This is a possible contamination source.
- Are the parts passing through any other spray booths using different colors on the way to the cure ovens? This can cause contamination.
- Is there excessive air turbulence in the oven? This will affect uniform coating.
- Does coating take place in an environmentally controlled room? If not, the risk of contamination from outside sources rises.
- Does the room have positive air pressure? Air pressure should be greater inside the room to force airborne particulate out.
- Does the operator have controlled access to the spray area or are there doors being opened and closed allowing contaminants into the spray area? If the operator cannot control booth access, the danger of outside contamination or wind currents affecting adhesion rises.

PROTRUSIONS

Uniform protrusions on parts point to a problem with the powder. Random or nonuniform protrusions indicate a process issue.

If the protrusions are in a particular location on the parts, this indicates an application problem. The size and shape of the protrusion—round, spherical, or fibrous—help identify the source of contamination.

A rub down with a white towel might reveal residual soil or contaminants on the parts.

If an operator hangs clean Q-panels or another substrate on the line just in front of the booth, this might indicate if the problem is related to the parts or pretreatment. The operator also can use a lint-free rag to do a solvent cleaning on some parts before they enter the booth.

If shot blasting is done in the building, this could leave fine particles floating in the air. Weld spatter or grinding dust also could cause protrusions. If parts are handled after the washer, contamination may be picked up.

What is the film thickness of the coating? What is recommended? Most coatings are specified from 1.8–2.2 mils (46–56 μm) thick. Coatings less than 1.5 mils (38 μm) may show an unacceptable surface.

If protrusions occur only with powder that is blended with reclaim, but not with virgin powder, this indicates the material is picking up some contamination in the booth and reclaim module. If the problem occurs with other powders, it indicates there is a general problem. If protrusions are on the surface of the coating, the contaminant is likely to be airborne. If the contamination is embedded, the source could be contaminated reclaim.

Reconditioning sieves are either rotary or vibratory and come in different sizes. Most operations use a sieve that is 60 mesh. Using a screen that is 40 mesh is too large, while at the other extreme, a 100-mesh screen could cause blinding of the screen.

Cleaning equipment once a shift is normal. Guns, hoses, and venturis should be checked for impact fusion that can contaminate the powder.

Other items to remember when dealing with protrusions include:

- Another source of contamination could be parts falling off hooks, racks, and conveyors. Not cleaning off hooks after they are burnt off also can cause problems.

- Surging and spitting can look like foreign contaminants. Surging can be caused by air settings that are too low.
- Powder should be checked again for quality after one year.
- Storage conditions for powder should not exceed 80° F (27° C).

CRATERS, PINHOLES, AND FISHEYES

Table 15-8 gives troubleshooting tips for disturbances found in cured film.

The size and frequency of craters, pinholes, and fisheyes help determine the source of the contamination. The problem may be unique to the particular powder if other powders have been sprayed without any problems.

A white-towel test is a quick and efficient way to establish whether there is any soil left on the substrate. If the substrate surface is highly polished, it may contain cleaning compounds. Castings should be degassed.

The pretreatment system must be cleaned and recharged regularly so that parts break free of water and also pass the white-rag test. If there is moisture on the part's surface, it can cause craters and pinholes.

A white rag should be used to test for air purity at the end of the hose. Compressed air can be a source of moisture. Filters on an air dryer are necessary and they should be located as close to the booth as possible.

Incompatibility between powders can cause craters. Some acrylics are especially bad. Also, urethanes can contaminate epoxies. Silicone spray lubricants used in the plant can cause large fisheyes.

It is possible that some of the people handling parts are using hand creams or deodorants that are incompatible with powder coatings.

COATING CHOICE

Regardless of the substrate, the operator must determine finished product requirements by looking at the demonstrated film performance and asking:

Table 15-8. Troubleshooting disturbances in cured film

Trouble	Possible Cause	Possible Solutions
1. Dust, precured, or other coarse material	1. Dust or other coarse material on the metal surface	1. Check the pretreatment.
	2. Dust or other coarse material in the powder	2. Check the powder and locate the cause of contamination. If necessary, clean up the installation and use fresh or sieved powder.
	3. Pre-cured material from original powder that is stocked according to instructions	3. Check with manufacturer.
2. Matting of powder surface	1. Contamination with other powder (based on other raw materials)	1. Clean up the installation; if necessary, contact powder supplier.
3. Orange peel	1. Warming up of the coating material is too slow or fast	1. Check curing cycle and the curing oven; if necessary, contact powder supplier.
	2. Powder type too fast or too coarse for particle size distribution	2. Contact powder supplier.
	3. Moisture contamination	3. Replace the powder.
	4. Heat damage of the powder	4. Replace the powder.

Table 15-8. (continued)

Trouble	Possible Cause	Possible Solutions
4. Cratering	1. Contamination with other powder (based on other raw materials)	1. Clean up the installation; if necessary, contact powder supplier.
	2. Bad pretreatment such as with remaining greases	2. Check the pretreatment and, if necessary, contact the pretreatment supplier.
	3. Contamination with incompatible materials from the spraying area such as silicones	3. Check for the presence of incompatible materials.
5. Pinholing	1. Humidity of the powder too high	1. Check storage facilities. Powder should be stocked at room temperature in closed packing (maximum humidity 75%).
	2. Air entrapment	2. Preheat objects over 320° F (160° C) to off-gas.
	3. Air entrapment due to chemical reaction	3. Keep coating thickness below 3,937 µin. (100 µm).

1. How does it apply to the parts?
2. How much does its cost affect the bottom line?
3. What is its appearance?

The operator must be sure to have a balance of these variables. He or she should ask the coating manufacturer to assist in determining the best choice.

The operator also should ask the powder account manager if any formulated products are in stock. This reduces cost considerably. If the manufacturer must formulate the powder to demand, the operator should ask for a reasonable estimate to ensure the product does not exceed production budgets.

Job Descriptions and Policies

POWDER COATING POSITIONS

Members of today's modern work force are aware that the ability to properly manage or lead employees is greatly enhanced by the availability of written job descriptions of tasks to be performed in various job positions.

Written job descriptions help employees understand exactly what is expected of them. In addition, they give management the necessary tools to gage if employees are fulfilling their job duties at review time.

A company policy manual is a tool that also lets employees clearly understand the company rules and guidelines.

Following are some examples that may be helpful when writing job descriptions for workers in the powder coating industry. The material in this section is meant to serve as a reference guide only and it in no way represents any specific recommendation to a particular company. The job descriptions and policies included here are merely guidelines for creating similar written job documents. No promotion of any specific method is implied.

In addition, the following examples may not represent readers' actual management criteria, due to the large variety of companies. However, the material does address the traditional roles of management such as organizing, planning production activities,

and anticipating the employees' tasks required in his or her individual jobs.

Painter Classes A, B, and C

Major Duties—Class A

A Class A painter needs to:

- have the required skills to apply and produce Class A industrial finishes on a continual basis;
- have at least one year of experience as a Class B painter;
- maintain good or better attendance;
- be a team player, help train others, and have a positive and helpful attitude;
- be familiar with and able to test finishes using approved test methods;
- be familiar with powder paint guns and related equipment;
- be able to determine if a product needs to be rejected and understand how to initiate corrective action;
- be familiar with powder booths and related equipment;
- be able to diagnose and fix powder paint equipment;
- read a control sheet and determine the proper powder for a job; and
- maintain proper powder availability levels.

A Class A pretreatment worker must have basic knowledge of the pretreatment field, including pretreatment chemicals, titrations of chemicals, substrates of ferrous/nonferrous materials, and power spray washers and equipment.

Pretreatment duties may include:

- periodic titrations of wash tanks to check pH and concentration levels;
- maintaining correct acidic and/or alkali levels in the system;
- keeping washer temperatures at posted levels;
- keeping chemical concentrates on order and at proper storage levels;

- testing for chlorine (if warranted) and total dissolved solids (TDS);
- maintaining the washer system for optimum performance during impingement, as well as for cleanliness;
- periodically dumping and cleaning the washer system;
- maintaining the pretreatment system and keeping the area clean; and
- maintaining accurate records for all applicable test areas.

Class B

Tasks and traits of a Class B painter include the following:

- works with minimum supervision;
- applies uniform coatings at proper mil thicknesses with no sags or light spots;
- keeps up with line-density demand;
- changes powder colors and chemistries; and
- adjusts powder coating system to regulate amount, flow, and deflection of powder pattern.

Class C

Class C workers are hired employees or painters in training. These employees:

- apply touch-up paint as required; and
- work other duties as assigned.

Duties

Other job duties for painters include:

- keeping equipment clean and in good operating condition (both inside and outside);
- keeping booth filters in proper condition;
- making sure the floor is clean and mopped; and
- maintaining safety standards and equipment.

Equipment

Painters need to be well versed on the following:

- pH meter (a meter to test for the relative degree of acidity or alkalinity of a liquid);
- TDS meter (a meter to test for total dissolved solids);
- chemical concentration meter (a meter to test for the total concentration level of a product in a particular amount of liquid);
- mil-thickness gage (gage to test the uniform thickness of a coated substrate);
- MEK test (method to test for the proper cure of a substrate); and
- crosshatch test (to test for cure and/or proper pretreatment).

Machines or equipment used continually by painters includes:

- powder guns,
- hoppers and related equipment,
- paint booths, and
- cure ovens.

The following machines, equipment, and tests are only used occasionally by painters:

- pH meter,
- chemical-concentration meter,
- mil-thickness gage,
- MEK-test methods, and
- crosshatch test.

Education and Experience

No formal education is necessary to be a painter. Less than high school is acceptable. An employee does not require previous experience for this position. It should take an employee approximately two weeks or less to become generally familiar with the details of the duties involved.

Supervisory Level

A limited amount of supervision is ordinarily required of painters. The work is generally assigned by a supervisor, but performed to a large extent on its own, with some choice of method. Decisions are usually reviewed before becoming effective.

The painter's only supervisory responsibility is maintaining the standard in the industry. There are no job titles that are under the direct supervision of this position.

A painter has continuous contact with team members in other units. However, there is no contact with company customers and vendors, and only occasional contact with federal or state agencies.

Errors

Painters are likely to experience the following kinds of errors while applying paint:

- contamination,
- light spots,
- heavy spots, and
- uneven mil thicknesses.

Painters are likely to experience the following kinds of errors while performing pretreatment tasks:

- contamination,
- lack of adequate pretreatment,
- impingement,
- dirt under the painted topcoat,
- dumping of chemicals, and
- unnecessary use of wastewater chemicals.

Correction. Errors are often corrected by:

- properly trained and competently skilled painters who are familiar with all of the tools and equipment used to maintain equipment;
- painters who possess the knowledge to use the proper tools to determine and then correct a problem;

- employers who offer continuing education for operators including vendor training, seminars, tours, and in-house training programs; and
- having painters fill out long-term corrective action forms, which are submitted to their paint supervisors.

Effects. Negative effects of errors could include the following:

- rejected painted parts that have to be sent for rework;
- pretreatment contamination;
- improper pretreatment and/or impingement;
- corrosion failure;
- premature salt fog failure;
- adhesion loss;
- dirt found under painted topcoat;
- loss of production time; and
- loss of bath life and resultant dumping of chemicals, and unnecessary use of wastewater chemicals.

Other Aspects of the Job

A painter needs a higher-than-normal mental or visual alertness to perform his or her duties. High levels of visual and mental attention, concentration, and sustained visual alertness are required as well.

The job involves constant repetition using a conveyor system. Painters use the arms and shoulders continuously by moving in and around the parts; they lift powder paint boxes of up to 55 lb (25 kg).

Disagreeable job conditions the painter is exposed to include:

- noisy fan from the booth;
- possible physical contact with powder paint;
- overall job may be monotonous and stressful due to repetitive nature of automatic conveyor system;
- area smells strongly of chemicals and curing substrates;
- physically cleaning inside of washer equipment requires painter to get wet and dirty; and
- painter is exposed to caustic chemicals.

General Labor

Loaders and Unloaders

The following information applies:

- Workers must load and unload related items onto or off of a conveyORIZED system.
- Workers must maintain good attendance.
- Parts must be hung in order, without gaps in sequence.
- A loader makes sure parts are in the load area and ready to be loaded.
- An unloader must insure that some bins are in an area for unloading and others are moved to the next appropriate area.
- Loaders must assist engineering workers to create racking designs that allow for easier and/or more efficient loading.
- Positions require lifting up to 70 lb (32 kg).
- Workers must maintain, clean, and repair related equipment.
- Positions involve keeping areas neat, clean, and safe.
- Workers must be able to follow instructions.
- Loaders and unloaders must be able to work on a conveyORIZED system offering little or no downtime.
- Positions involve being able to work in high-volume areas.
- Workers must complete other duties as assigned.
- Workers must pack or wrap product and other related items.
- Workers must operate a tapping machine for chasing tapped threads.
- Workers must apply touch-up paint to bare areas.

Equipment. The following machines and equipment are used continually by loaders and unloaders:

- tapping machine,
- paint touch-up gun, and
- racking fixtures, bins, carts, etc.

Education and experience. Less than a high school education is acceptable for loader and unloader positions. In addition, no previous or related work experience is required for a person starting the job. It should take an employee two weeks or less to

become generally familiar with the details of duties involved to perform the job reasonably well.

Supervision. Loaders and unloaders require daily supervision to get advice, direction, and/or work assignments. They follow established methods and procedures, referring exceptions to the supervisor. Their decisions are usually reviewed before becoming effective.

Loaders and unloaders have continuous contact with team members in other units. However, they never have contact with company customers, vendors, or federal or state agencies.

Errors. There are several kinds of errors that are likely to occur while performing the jobs of loader and unloader.

Loader errors include:

- Parts may be sent to the wrong area for paint application.
- Parts may not be in the correct sequence.
- Parts may be hung incorrectly (upside-down, unsecured, etc.).
- Parts may be the wrong parts.
- The loader may not be able to keep up to speed or have parts to hang.

Unloader errors include:

- Parts may be damaged by the unloading operation.
- Parts may not get to their respective areas of assembly, manufacturing, or shipping.
- The unloader may not be able to keep up with production.

After loading and unloading, packaging errors that can occur include:

- damaged products;
- paint defects;
- improper packaging materials;
- threads not chased; and
- improper labeling and/or counts.

Correction. Primarily other team members or supervisors discover load area problems. It is helpful for loaders to ask paint supervisors about production loads for a shift. In addition, loaders and unloaders can ask for assistance with their jobs.

Errors can often be corrected by properly trained loaders and unloaders who are familiar with the tools and equipment needed to maintain the equipment. Utilization of the correct tools and knowledge to determine the existence of a problem is vital.

Errors can often be prevented through continuing education. Examples include vendor-taught training sessions, trade seminars, tours of other facilities, and in-house training programs.

Finally, loaders and unloaders can fill out long-term corrective action forms and submit them to their paint supervisors to remedy continuing problems.

Effects. The effects of loading and unloading errors include the following:

- A product that is hung incorrectly (for example, upside-down or unsecured, etc.) can cause a part to fall off of the conveyor system.
- A product that is hung out of order can cause the production schedule to change and possibly leave other areas temporarily without work.
- A part sent to the wrong area for paint application can result in rejection and/or production schedule problems.
- Production will slow when loaders fail to keep up with the conveyor.
- If the unloader cannot keep up with the conveyor, production could cease because the part must be unloaded. This could have an effect on other parts still in the system.
- A product that is improperly wrapped can damage the finished part; wrong counts can be sent to customers.

Other Aspects of the Job

The jobs of loader and unloader require close visual and mental attention and sustained alertness. In addition, there is constant repetition using arms, shoulders, and moving around the load/unload areas. There is an emphasis on following the parts' correct hang schedule.

Disagreeable job conditions include:

- continual heavy lifting involving up to 60 lb (27 kg); and
- area may be loud, and smell of chemicals, paint, and curing substrates.

Team Leader

Duties

The team leader is a working position that requires good interpersonal employee relationship skills. The following tasks apply to the position:

- supervises production personnel;
- assists with instructing employees;
- assists with assigning work schedules, reviewing work, and planning the work of others;
- helps coordinate activities;
- assists with allocating personnel;
- acts on employee problems;
- aids with leading and training for pretreatment, liquid paint, powder paint, loading, unloading, masking, unmasking, and scheduling;
- cleans and fixes related equipment;
- maintains inventory control and general shop safety;
- keeps area neat, clean, and safe;
- works in high-volume areas; and
- other duties as assigned.

Equipment

Machines used by the team leader include all paint shop-related equipment. The team leader should have knowledge of industry paint ovens, washers, and booths.

Education and Experience

No formal education is necessary to be a team leader. Less than high school is acceptable. Although this candidate does not need a

high school or college education, he or she should have three months to one year of previous experience. It should take an employee approximately three months to become generally familiar with the details of the duties involved.

Supervision

The position of team leader requires little or no supervision. This position has continuous contact with team members in other units. A team leader may have some contact with company customers, vendors, or federal or state agencies. Additionally, decisions made by the team leader are usually reviewed before becoming effective.

The following supervisory responsibilities are part of the team leader's job:

- instruction,
- allocation of personnel,
- assignment of work,
- resolution of employee problems,
- reviewing and planning the work of others,
- maintaining standards, and
- coordination of activities.

Listed below are the job titles under the direct supervision of the team leader. Listed in parenthesis next to the job title is the number of team members per team for each particular job title—this amount is normally around 20 employees:

- loaders (2 or more);
- unloaders (2 or more);
- maskers (1);
- packagers (3 or more);
- liquid painters (1); and/or
- painters (2 or more).

The team leader has continuous supervisory authority over immediate team members and over outside vendors, and occasional supervisory authority over team members in other units.

Errors

Several kinds of errors are likely to occur while performing the job of team leader. Errors can occur if the team leader does not have good interpersonal and employee relationship skills. Other errors can occur if the team leader fails to:

- set up the schedule for production demand;
- keep the paint shop Class A clean;
- keep tabs on inventory; or
- initiate corrective action.

Correction. Errors are ordinarily checked or discovered by properly trained and competently skilled team leaders who are familiar with all tools, equipment, and machinery to produce a finished product. Through the use of interpersonal skills and tools to determine if a problem exists or not, a correction can often be made.

Errors can also be corrected through continuing education, vendor training, seminars, tours, and in-house training programs.

In addition, team leaders can fill out long-term corrective action report forms and submit them to paint supervisors to remedy continuing problems.

Effects. If the team leader does not have good interpersonal skills, the team attitude and product will suffer. If the team leader does not have knowledge of equipment and tools, the employees will not have proper direction, other than from an engineering point of view. If the team leader does not understand an employee's job function, the employee will not be able to look for proper direction from the team leader. Improper direction will also lead to mistakes, rejects, and downtime.

Other Aspects of the Job

More than normal mental or visual alertness is required of a team leader. In addition, the job involves continual walking on demand.

Paint Supervisor

Duties

A paint supervisor has the following duties and expectations:

- supervises production personnel;
- good or better attendance;
- instructs employees;
- assigns work schedules;
- reviews work;
- plans work of others;
- coordinates activities;
- allocates personnel;
- acts on employee problems;
- transfers/promotes employees;
- disciplines employees;
- files first report of injury and follow-up reports;
- puts production schedule into effect for daily production;
- recommends salary increases; and
- selects new hires and discharges employees.

The paint supervisor is responsible for the following areas:

- pretreatment,
- wet paint,
- powder paint,
- loading,
- unloading,
- masking,
- unmasking,
- scheduling,
- leads,
- packaging,
- inventory control,
- training, and
- general shop safety.

The paint supervisor must be quality minded. In addition, he or she is responsible for industrial Class A paint jobs, as specified by prints or related specifications. The paint supervisor must perform other duties as required.

Equipment

The paint supervisor should be able to operate all paint shop-related equipment and have exceptional knowledge of paint application, industry paint ovens, washers, booths, and more. Prior experience with wet paint, powder paint, and pretreatment must exist as well as hands-on experience in a supervisory capacity in these areas.

Education and Experience

Paint supervisors do not need a high school or college education, but they do need 1–3 years of previous related work experience.

It should take an employee about 6 months, with the required experience, to become generally familiar with the details of duties involved to do this job reasonably well.

Supervision

A paint supervisor requires little or no direct supervision. Paint supervisors usually have a wide choice in the selection and development of work methods within a broad framework of general policies. Decisions made by paint supervisors are usually reviewed before becoming effective.

Supervisory responsibilities that are part of the paint supervisor job include:

- instructing,
- allocating personnel,
- assigning work,
- acting on employee problems,

- reviewing work,
- selecting new employees,
- planning work of others,
- transferring/promoting,
- maintaining standard,
- disciplining,
- coordinating activities,
- discharge, and
- salary changes.

Listed below are the job titles under the direct supervision of the paint supervisor (listed in parenthesis next to the job title is the number of team members per team for each particular job title; this amount is normally up to approximately 40 employees):

- team leaders (3);
- head packer (3);
- loaders (6 or more);
- unmaskers (1);
- unloaders (6 or more);
- maskers (1);
- packagers (12);
- liquid painters (6 or more); and
- powder painters (1).

This position has continuous contact with team members in other units and outside vendors. There is occasional contact with company customers and federal or state agencies.

Errors

Errors can occur if the paint supervisor does not have good interpersonal employee relationship skills. The paint supervisor may not be able to set up a schedule for production demand or keep the paint shop Class A clean. Errors can be made if he or she does not keep tabs on inventory or if corrective action is not initiated when necessary.

Correction. Errors are ordinarily checked or discovered by properly trained and competently skilled paint supervisors who

have good interpersonal skills and are familiar with all tools, equipment, and machinery needed to produce a finished product.

By properly utilizing tools, as well as having the proper knowledge to troubleshoot problems, a correction can often be made. Continuing education through vendor training, seminars, tours, and in-house training programs is helpful as well. In addition, paint supervisors can fill out long-term corrective action reports to remedy continuing problems.

Effects. If the paint supervisor does not have good interpersonal skills, the team attitude and product will suffer. If the supervisor does not have good knowledge of equipment and tools, employees will not have good direction. If there is not an understanding of each employee's job function, employees will not be able to look for proper direction from the supervisor. Improper or misdirection from the supervisor leads to mistakes, rejects, and downtime.

Other Aspects of the Job

The level of mental or visual alertness required for paint supervisors is more than normal to perform the duties of this position. Work is frequent, but with occasional breaks. A disagreeable job condition is continual walking on demand.

Paint Manager

Duties

The duties and expectations of a paint manager include:

- working with the supervisor of production personnel;
- maintaining good attendance;
- instructing employees;
- assigning work schedules;
- reviewing quality of work;
- planning work of others;
- coordinating activities;
- allocating personnel;

- acting on employee problems;
- transferring/promoting employees;
- disciplining employees;
- reporting injury/follow-up reports;
- putting daily production schedule into effect;
- recommending salary increases; and
- selecting new hires and discharging employees.

The paint manager is responsible for the following:

- pretreatment,
- wet paint,
- powder paint,
- loading,
- unloading,
- masking,
- unmasking,
- scheduling,
- leads,
- packaging,
- inventory control,
- training, and
- general shop safety.

Overall, the paint manager must assure quality. The paint manager is responsible for industrial Class A paint jobs as specified by prints or related specifications. He or she must also perform other duties as required.

Equipment

The paint manager should be able to operate all paint shop-related equipment and have exceptional knowledge of paint application, industry paint ovens, washers, and booths. The manager must have prior hands-on experience with wet paint, powder paint, and pretreatment, as well as supervisory experience in these areas.

Education and Experience

The paint manager does not need a high school or college education, but does require previous experience of 1–3 years. It generally will take a paint manager about 6 months to become familiar with the details of the duties involved with this job.

Supervision

A paint manager requires little or no direct supervision and has a wide choice of selection and development of work methods within the broad framework of general policies. Decisions of the paint manager are usually reviewed before becoming effective.

Supervisory responsibilities that are part of the paint manager's job are:

- instructing,
- allocating personnel,
- assigning work,
- acting on employee problems,
- reviewing work,
- selecting new employees,
- planning work of others,
- transferring/promoting,
- maintaining standards,
- disciplining,
- coordinating activities,
- discharges, and
- salary changes.

The following list of job titles are under the direct supervision of the paint manager (listed in parenthesis next to the job title is the number of team members per team for each particular job title; this amount is normally up to approximately 40 employees):

- team leaders (3);
- head packers (3);
- loaders (6 or more);
- unloaders (6 or more);

- maskers (1);
- unmaskers (1);
- liquid painters (6 or more);
- powder painters (1); and
- packagers (12).

This position has continuous contact with team members in other units and outside vendors. There is occasional contact with company customers and federal or state agencies.

Errors

Several kinds of errors are likely to occur on the job for the paint manager. The manager may not have good interpersonal employee relationship skills or be able to set up the schedule for production demand. These factors can cause errors. The manager may not be able to keep the paint shop Class A clean or keep tabs on inventory, also causing errors.

Correction. Errors are ordinarily checked or discovered by properly trained and competently skilled paint managers with the interpersonal skills needed to manage a team.

A paint manager can fill out long-term corrective action reports to remedy continuing problems.

Effects. If the paint manager does not have good interpersonal skills, team attitudes and products will suffer. If the manager does not have good knowledge of equipment and tools, the employees will not have good direction. If the manager does not understand each employee's job function, the employee will not be able to look for proper direction from the manager. Improper or misdirection from the paint manager will lead to mistakes, rejects, and downtime.

Other Aspects of the Job

Higher than normal mental or visual alertness is required for this job with frequent activity, but with occasional breaks. Disagreeable job conditions include continual walking on demand.

Silk Screener

Duties

The duties and expectations of the silk screener include:

- proficiency at screening;
- good attendance;
- mixing all inks to applications;
- keeping ink on inventory;
- keeping screen area neat, clean, and safe;
- cleaning and fixing related equipment;
- checking dispatch list for upcoming jobs;
- inspecting screens for quality according to upcoming jobs;
- maintaining screens;
- ability to follow work instructions;
- ability to work in high-volume areas; and
- other duties as assigned.

Equipment

Silk screeners use the following machines and equipment:

- screens,
- ovens,
- fixtures,
- squeegees,
- solvents, and
- related equipment.

Education and Experience

No formal education is necessary to be a silk screener. Less than a high school education is acceptable. An employee does not require previous experience for this position. It should take an employee approximately two weeks or less to become generally familiar with the details of the duties involved.

Supervision

Silk screeners require occasional supervision, with most duties being repetitive and related to standard instructions and procedures as guides. Unusual problems are referred to supervisors. Decisions are reviewed before becoming effective. Maintaining standards is the only supervisory responsibility of this job.

There are no job titles under the direct supervision of the silk screener. There is frequent contact with team members in other units and occasional contact with outside vendors. Silk screeners never have contact with company customers or federal or state agencies.

Errors

Errors likely to occur on the silk screener's job include:

- The ink may be improperly mixed.
- Pigment may not be suspended properly.
- Solvent may not be mixed thoroughly.
- Viscosity may not be proper.
- Wrong color may be mixed.
- Paint may not be mixed when it is needed.
- Screens may not be clean.
- Equipment may not be ready for production.
- The fixture may not be ready for application.
- The ink or screen may not be ordered.
- Unsafe storage practices may occur.

Correction. Errors are ordinarily checked or discovered by properly trained and competently skilled silk screeners who are familiar with all tools, equipment, and machinery required to produce a finished product. Silk screeners also possess the knowledge to use the tools to determine if a problem exists or not so a correction can be made.

Errors also can be corrected through continuing education, vendor training, seminars, tours, and in-house training programs.

Silk screeners can fill out long-term corrective action report forms and submit them to paint supervisors to remedy continuing problems.

Effects. If the wrong color were to be screened, the part may be saved for an upcoming job, or sandblasted and reworked to the proper color. If the tint is wrong prior to the ink application, the part will most likely be rejected after screening.

Other Aspects of the Job

Mental or visual alertness levels required of silk screeners are highly concentrated, steady, and sustained.

Disagreeable job conditions for silk screeners include:

- constant use of arms with repetitive motions;
- area may be loud;
- smell of chemicals/solvents;
- smell of curing substrates; and
- may come into contact with ink/solvent, along with solvents used to clean paint-related equipment.

COMPANY POLICY MANUAL

Sound employment policies include principles that an organization uses to govern its employee relations in a fair and consistent manner. Having all policies and procedures in one manual helps employees be aware of what is expected. It can also prevent misunderstandings about employer policies.

Supervisors and managers are better able to implement policies that are clearly communicated in writing. Written policies also help employers document compliance with the unending tangle of employment laws and regulations. For example, the Supreme Court has indicated that employers can help protect themselves against liability for sexual harassment by having an effective policy against it that includes a complaint procedure. In addition, the Federal Family and Medical Leave Act requires employers to provide written information regarding employee rights and employer obligations under the act.

Information to Include

A policy manual might have the following types of information:

- personnel responsibilities;
- model cover and president's letter;
- functions of the manual;
- names of personnel and employer-employee relations managers;
- employment-at-will and Equal Employment Opportunity statements;
- productive work environment and harassment policies;
- hiring and employment agreements;
- orientation and training information;
- transfer, promotion, hours of work, and outside employment policies;
- employee classifications;
- layoff and recall, termination of employment, and retirement policies;
- benefits, vacation, and holiday information;
- lunch facilities, educational assistance, and employee counseling information;
- recognition/service awards;
- company products/services;
- relocation, athletic, and recreational programs;
- policies on absences from work, attendance/punctuality, short-term absences, leaves of absence, rest breaks, and meal breaks;
- standards for personal conduct, behavior of employees, personal appearance, and finances;
- guidelines for handling customer relations, communication systems, conflicts of interest, and confidentiality;
- disciplinary procedures for drug and alcohol use on the job; work areas; and employee safety;
- maintenance, personal property, and solicitation procedures;
- parking and security policies;
- guidelines for pay practices, salary administration, performance appraisals, severance pay, and job evaluations;
- dispute-resolution guidelines; and

- policies on reimbursement for work travel, automobile usage, business entertaining, work/civic clubs, work organizations, and trade/professional association membership.

Creating a Policy Manual

If a company does not have a formal policy and procedures manual, it should begin by deciding which policies to include. Sometimes insurance companies can help decide what would be appropriate.

When creating company policies, a company should consider:

- the culture of its organization and recurring issues or problems;
- any memos on policy topics (such as vacation and holiday schedules);
- past practices (for example, what has been done to address a particular employee relations issue); and
- practices followed by other organizations in the industry (including vacation lengths and leave allowances).

At a minimum, most employers develop policies on:

- at-will employment;
- pay procedures;
- benefits (including any paid vacation, sick leave, holidays, and other forms of leave);
- meal and rest breaks;
- personal conduct (work rules);
- attendance and punctuality;
- sexual and other forms of harassment;
- Equal Employment Opportunity;
- disciplinary procedures; and
- termination.

Conclusion

A special note of caution is always in order. No policy manual or handbook should ever be issued or revised without a final review and check-off.

To meet the needs of the powder-coating industry, all companies should require all employees to maintain good attendance and positive attitudes that promote team environments and assure continued growth of the company. This is the general basis for any employee to move upward through any company.

Lean

MANUFACTURING WITHOUT WASTE

The lean manufacturing paradigm is simple. Take a process. Focus on the intent of the process. Eliminate all parts of the process that do not contribute to the value or meet the intent. Then, look at each remaining part and work continually to lower its cost, make it timelier, and improve the quality of results (Jordan and Michel 2001).

Lean manufacturing is manufacturing without waste. In some factories, as much as 80% of labor, material, and other resources do not contribute to customer satisfaction. By definition, this is waste. Here is a partial list of activities, behaviors, and conditions that can lead to waste:

- facility layout,
- excessive setup times,
- incapable processes,
- poor preventive maintenance practices,
- uncontrolled work methods,
- lack of training,
- lack of workplace organization,
- lack of supplier quality and reliability,
- lack of concern or accountability,

- passing on defective parts,
- not communicating improvements, and
- redundant counting or ticketing (Conner 2001).

Lean facilities are designed to allow companies to react quickly to customers' requirements. Quick reaction time is the basis for reduced inventories, improved cash flow and inventory turns, superior productivity, and higher quality.

Many times, the success of a powder-coating firm is contingent upon the company's adoption of lean manufacturing principles. This is especially true for smaller paint shops, because customers are looking for cutting-edge service, quality, and price. Without a commitment to a lean operating process, the operating costs can exceed the income needed to continue productively.

Lean manufacturing has kept America competitive in many industries, despite the cheap labor that comes with increasing skills abroad.

Lead-time Reduction

In most cases, especially in smaller paint job shops, keeping lead-time promises are paramount to the customer. Making sure a customer's parts are processed in a relatively short lead time helps to insure the relationship with that customer. Favorable lead times produce acceptable finish times. This is usually one of the biggest customer expectations.

Raw Material Reduction

It is important to have enough powder to completely finish a job, and maybe a little extra in case of problems during the application. However, management and/or purchasing departments should put an emphasis on buying powder only after the part has been properly measured for the geometric surface area that needs to be coated. It is very costly to buy powder without using a formula, not to mention the fact that powder stored on shelves eventually will be outdated. Storage is also a waste of space. The purchase price on each pound of powder for buying in bulk is not

justified if the powder goes bad or is not needed again. Usually, it turns out that there is not another job on which to utilize the powder.

Work-in-Process Reduction

It would be nice to process every order in the order of receipt, but this is not usually preferable. Usually, the most economical choice is to group parts by color. Grouping by color reduces work-in-process (WIP) by speeding the color-change process. It usually takes much more time to change between colors such as black and white, than colors such as tan, almond, and white. Grouping by color keeps a process focused by minimizing contamination.

If there are parts requiring specialty colors, it may be preferable to coat these parts before the normal day of operations, or even during lunches or breaks. It severely handicaps production to put gaps in the conveyor in the batch booths to paint these parts. The time it takes to clean the hoppers and booth, apply the powder to the parts, as well as clean the hoppers and booth for the next job, must be taken into consideration. Again, this applies to specialty colors that do not match colors that can be grouped.

Finished Goods Inventory Reduction

Finished goods inventory can be viewed in two scenarios. First, if it is certain that a customer will be purchasing the same parts again, it might be advisable to paint the parts when they are available, thus reducing the downtime for color changes. It also helps to give the lead time a boost on a future customer order and make the customer happy. The drawback is that customers tend to think every part can be turned around in the same shortened lead time when it has been done once. Parts take up space and space costs money. It is important to let customers know precisely when parts will be done and what the schedule is for them to be picked up or delivered. Do not allow parts to sit around a shop potentially getting damaged or dirty. The most important aspect of shipping parts is the billing. Usually, customers do not expect to be billed until the parts are shipped.

Increasing Cash Flow

Increased cash flow can help guarantee a company will be in business tomorrow. It may help in times of recession or when a company wants to purchase new equipment, or simply when workers need to maintain the equipment.

Increased Inventory Turns

As previously stated, a company should try to turn its stock around frequently. “First in, last out” is another way of saying keep the powder inventories moving. Again, the more powder a company has in stock means the more powder it will eventually need to move. A company should try decreasing inventory. This will increase cash flow by saving time and space.

Workmanship and Quality

Improving workmanship and quality will help guarantee customer satisfaction. High-quality pretreatment and powder application is a function that can be performance tested. A company will receive favorable comments from customers, which will equate to increased revenues. Part defects, poor shipment times, and rework costs lead to dissatisfied customers. This disrupts WIP for everyone. A company should give its customers quality assurance certificates.

On-time Shipments

A firm must deliver parts on time in the powder coating business. Customers expect it. It is important to focus on batching colors to insure productivity levels are as rapid as possible. It is also important to make sure quality is maintained so that time is not wasted in reworking parts. Many customers track shipment times; therefore, a company should not tell customers it will ship when it may know it is not possible. It is important to keep shipping areas clear of stocked product or powder storage. These areas can then be utilized for easy shipping access.

IMPROVING PRODUCTIVITY BY ELIMINATING WASTE

It is important to eliminate every area of waste within the paint shop. Improving line density is paramount. The more parts painters can paint per hour, the more productivity the company will see. Many times a company will hang one or two parts per hook, when it should be hanging 20 or 30 parts per rack. It is important not to waste this space. Powder colors should be optimized to eliminate waste of color-change time. It may be cost justified to add another painter to compensate for added line density.

Floor Utilization

Paint systems should be designed to allow access to pretreatment, powder application, and receiving/shipping areas. Keeping a staging area for raw parts will insure that flow is not compromised. All empty skids and crates should be taken off of the shop floor. The shipping area should be cleared of debris and all painted parts should be shipped. A company should have someone bring in boxes for each job and take away any extras as soon as the job is complete. It should also provide enough space for working on the entire job. Areas that are too congested tend to cause loss of parts, which can delay shipment of the product.

Work Cells

Work cells are at the heart of lean manufacturing. The benefits of work cells are many and varied. They increase productivity and quality. Cells simplify material flow, management, and even accounting systems. Flow is critical to paint application areas.

Work cells appear simple. But beneath this deceptive simplicity are sophisticated sociological, biological, and technical systems. Proper functioning of work cells depends on the subtle interactions of people and equipment. Each element must fit with the others in a smoothly functioning, self-regulating, and self-improving paint operation.

Paint Layout

Layout or physical arrangement is the last step in designing an effective work area. Done well, the layout enhances teamwork and material flow. Done poorly, the layout can prevent proper functioning of the work area.

LEAN RULES

Eliminate Waste

The first rule of lean operations is to eliminate waste. Lean principles suggest that every consumable is a candidate for scrutiny. The burden is on the service to prove not only that it adds value to the final product, but also that it is the most efficient way of achieving that value.

Minimize Inventory

The second rule of lean is that inventory is wasteful. Inventory consumes resources, slows response time, hides quality problems, gets lost, degrades, and becomes obsolete.

Maximize Flow

Maximize flow—it is important to attempt to produce products in hours, instead of days or weeks. Reducing WIP will trim the cycle time.

MANAGEMENT RESPONSIBILITY

Quality System

Management has a responsibility to create a quality-control policy that is defined, documented, understood, implemented, and maintained. This policy should list responsibilities for all personnel who specify, achieve, and monitor quality.

The quality system should include:

- in-house verification of resources defined, trained, and funded;
- the name of a designated management person who oversees the program;
- preparation of procedures; and
- implementation of procedures.

Contract Review

Incoming contracts and purchase orders should be reviewed to see whether the requirements are adequately defined, in agreement with the bid, and can be supplied.

Design

Design control should include the following aspects:

- The design project should be planned.
- Design-input parameters should be defined.
- Design output, including crucial product characteristics, should be documented.
- Design output should be verified to meet input requirements.
- Design changes should be controlled.
- Generation of documents should be controlled.
- Distribution of documents should be controlled.
- Changes to documents should be controlled.

Purchasing

Potential subcontractors and sub-suppliers should be evaluated for their ability to meet stated requirements. Requirements should be clearly defined in contracting data. Effectiveness of the subcontractor's quality-assurance system should be assessed.

Customer-supplied material should be protected against loss or damage.

The products should be identified and traceable by item, batch, or lot during all stages of production, delivery, and installation.

Process Control

Production processes need to be defined and planned. Production should be carried out under controlled conditions through documented instructions, in-process controls, approval of processes and equipment, and criteria for workmanship.

Special processes that cannot be verified after the fact should be monitored and controlled.

Inspection and Testing

Incoming materials need to be inspected or verified before they are used. In-process inspection and testing should be performed. Final inspection and testing should be performed prior to the release of a finished product. Records of inspections and testing should be kept.

Inspection/Measuring/Testing Equipment

Equipment to demonstrate conformance is used in the following ways:

- Identify measurements to be made.
- Identify affected instruments.
- Calibrate instruments (procedures and status indicators).
- Periodically check calibration.
- Assess measurement validity if found to be out of calibration.
- Control environmental conditions in powder application and storage areas.
- Measurements of equipment capabilities should be known.
- Test hardware or software should be checked before using and rechecked during use.

The status of inspections and tests needs to be maintained for items as they progress through various processing steps. Records should show who released a conforming product.

Nonconforming products must be controlled to prevent inadvertent use or installation. The review and disposition of nonconforming products should be formalized.

The following steps should occur during the corrective action phase of production:

- Problem causes need to be identified.
- Specific problems and their causes need to be corrected.
- Effectiveness of corrective actions needs to be assessed.

Handling, Storage, Packaging, and Delivery

The following standards for handling, storage, packaging, and delivery should be developed and maintained:

- Handling controls must prevent damage and deterioration.
- Secure storage should be provided.
- Product in stock needs to be checked for deterioration.
- Packing, preservation, and marking processes must be controlled.
- The quality of a product after final inspection must be maintained. This includes delivery controls.
- Quality records should be identified, collected, indexed, filed, stored, and maintained.
- Internal quality audits should be planned and performed. The results of these audits should then be communicated to management and any deficiencies found should be corrected.
- Training needs to be identified and then provided. It is important to keep in mind that some tasks may require qualified individuals. Accurate records of training sessions should be maintained.
- Servicing activities need to be performed to written procedures. In addition, servicing activities should meet requirements.
- Statistical techniques in a company need to be identified. These techniques can then be used to verify the capabilities of a process and the characteristics of a product.

CYCLE TIME

When a company's deadline looms and the parts are far from ready, workers often stay overtime to rush through important functions. It is at these times that workers tend to skimp on testing and quality assurance to get a product out the door. Then a company must resign itself to customer complaints and frayed nerves. It is a never-ending cycle that always seems to have the same pattern of never having enough time to do things the right way. Still, customers continue to want faster service and competitors are offering to deliver it.

Shortening cycle time can give a company a competitive edge. Delivery ahead of competitors and meeting tight schedules means a company profits more. Even if a company has no competitor, the faster it paints parts, the more business opportunities it can accept. Even if a company has no market-driven need to do its work faster, just having the ability to do so means it has a competitive advantage. In general, requirements will be firmer because there will be less time for them to change.

Half of the causes of unnecessary delays that a firm may not have paid much attention to such as incompatible tools and overly complex production processes are simply a matter of wrong priorities.

To shorten cycle time, a company must increase throughput and/or decrease WIP. However, it is hard to increase throughput without increasing WIP. The smart approach is to reduce the WIP. The three causes of excess WIP are variability, complexity, and barriers or bottlenecks.

Repeated actions create more WIP. This means added cost and introduced delays. Much rework comes from simple things: rushing (causes more errors), communication (which may result in doing the wrong thing), and inadequate training (wasting time learning and making mistakes on the job). A company can improve cycle time by attacking these fundamental problems, but it must pick its battles. Once a company makes a list of the tasks that waste the most time and resources, it can then reduce or eliminate them. A company can next make another list and repeat the process.

Ultimately, a firm should design its processes to maximize efficiency. This is what lean improvement is really all about.

Sometimes, it is preferable to attack a job in small chunks. This way, mistakes are made and learned from on the early cycles, allowing performance at top speed in later cycles. Small batches reduce the amount thrown away or reworked when the rules are rewritten.

The optimal process is one where each step flows at the same speed, like boxcars in a train, rather than having each step go as fast as it can, like cars on a highway. Having everyone go as fast as possible can be more harmful than good, because people end up getting in each other's way.

By attacking the root causes of flow problems, a company can improve its delivery schedules permanently. Dealing with causes instead of symptoms saves money and improves product quality. The techniques are not hard. Simply apply basic principles in a methodical fashion, be open to new ways of doing work, and remember that competitors are constantly striving to be faster.

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UV Curing Techniques and Processes

*Contributed by David Hagood
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Ultraviolet (UV) curing is a chemical reaction produced when ultraviolet light is focused onto specially formulated inks, coatings, or adhesives. The UV light acts as a catalyst to polymerize the material. The amount of cure depends on several variables. These variables include formulation and thickness of material, speed of process, UV-light wavelength, intensity of UV energy, and exposure time of UV to substrate that is being cured.

UV light is the part of the electromagnetic spectrum between 7.9–17.7 $\mu\text{in.}$ (200–450 nanometers). It is divided into different bands to describe certain wavelengths of energy. Although values for spectral bands vary depending on the source, the ranges for UV are:

- UVA—12.4–15.7 $\mu\text{in.}$ (315–400 nanometers);
- UVB—11.0–12.4 $\mu\text{in.}$ (280–315 nanometers);
- UVC—7.9–11.0 $\mu\text{in.}$ (200–280 nanometers); and
- UVV—15.7–17.5 $\mu\text{in.}$ (400–445 nanometers).

To properly cure UV material, the process user must know the energy intensity and the total energy or dosage. The UV intensity is the amount of UV energy delivered to a particular area, per

unit time. Units are measured in $\text{W}/\text{cm}^2 \times \text{seconds}$ or J/cm^2 . The UV total energy or dosage is the amount of UV energy delivered to a particular area. The units are measured in W/cm^2 (J/cm^2).

UV-LAMP SYSTEM BASICS

UV-lamp systems consist of five basic components: power supply, lamp head, bulb, reflector, and cooling mechanism. The following characteristics apply to these components:

1. The power supply provides electrical energy to the UV bulb. Several types of power supplies are available including ballast, transformers, and solid state. These can be simple, fixed output units, variable-stepped power units, or more flexible variable units.
2. The lamp head is the part of the system holding the UV bulb and reflector.
3. The UV bulb is a sealed quartz tube that contains a medium-pressure mercury vapor. The vapor emits UV light when it is energized by either voltage arc or microwave energy.
4. The reflector is rolled from highly polished aluminum sheet metal or formed from borosilicate into elliptical or parabolic profiles. Holes or slots in the reflector allow cooling air to pass through them. The holes or slots are engineered for size and location to provide optimal and balanced airflow across the bulb's length.
5. The cooling mechanism decreases the temperature of the components in the lamp head and maintains a consistent bulb temperature for optimal UV output. It also carries away infrared energy, a by-product of the UV process.

UV BULBS

The two commonly used types of UV bulbs in lamp systems typically applied in UV curing are electrode and electrodeless. Both styles are made from sealed, fused silica-quartz tubes. An electrode is built into each end of the electrode bulb. Both elec-

trode and electrodeless bulb styles are filled with an inert gas and a small amount of mercury, which is a silver-white metallic element that is liquid at room temperature. The mercury creates vaporized, UV-emitting gas plasma inside the quartz tube when it is energized by either a voltage arc or microwave energy. When energized, the bulb produces a bright white UV output. Mercury bulbs have a peak spectral output of around 14.4 $\mu\text{in.}$ (365 nanometers) and a concentration of around 10.0 $\mu\text{in.}$ (254 nanometers).

Additional elements can be added to the bulb to shift the spectral output. For example, if iron is added, the iron provides a red-dish tint to an un-energized UV bulb and a bluish coloration to the UV output. Iron concentrates the spectral output between 13.8–15.7 $\mu\text{in.}$ (350–400 nanometers).

Gallium can be added to the mercury bulb. Gallium is a bluish-white metallic element and it provides a yellowish tint to an un-energized UV bulb and a violet coloration to the UV output. Gallium bulbs have a spectral peak at around 16.4 $\mu\text{in.}$ (417 nanometers) and a spectral concentration at between 15.7–17.7 $\mu\text{in.}$ (400–450 nanometers). They often are used when a deeper cure is required or with white coatings containing titanium oxides.

UV-LAMP SYSTEMS COMPARISONS

There are two UV-cure systems and they are based on the method of lighting the UV bulb. These methods are electrodeless-lamp systems (also known as microwave-powered lamps) and electrode-lamp systems (also known as arc lamps).

With electrodeless-lamp systems, microwave power energizes the bulb. The concept can be compared to a typical microwave oven, but using much higher power. A transformer-based power supply provides power to a magnetron mounted inside the lamp head. The magnetron generates microwave power that is guided into the microwave cavity where the UV bulb is located. The microwaves penetrate the quartz bulb and heat the inert gas inside. The gas, in turn, heats the mercury and any other additives inside the bulb. Once the mercury heats sufficiently, it creates plasma that emits UV energy.

In an electrode-lamp system, the bulb is energized by creating an arc between two electrodes, one located on each end of the bulb. A ballast or transformer-based power supply provides power to the electrodes in the bulb mounted in the lamp head. Just like the microwave bulb, the arc heats the inert gas inside the bulb, which then heats the mercury in the bulb. At the right temperature, the mercury creates plasma and emits UV energy.

The difference in the way the bulb is started creates some inherent differences in the operating characteristics of lamp systems. For example, in electrode systems, because an arc is created between the two electrodes in the bulb, each time the bulb is lit, the electrode wears slightly. This results in a limited number of starts an electrode bulb has before it no longer reliably starts. (A microwave bulb has no electrodes to wear, so there is no limit to the number of starts.) A comparison of the typical warranted life of a 10-in. (25.4-cm) cure-length microwave bulb to a 10-in. (25.4-cm) cure-length, electrode-lamp bulb, reveals that the microwave bulb life is up to five times greater than the electrode bulb. The electrode bulb warranty typically limits the number of starts as well. Therefore, many electrode-lamp systems are designed with shutter mechanisms allowing them to stay on at a low power during line stoppages or break periods. The shutter blocks the UV light during the down period and simply opens when the line resumes running. With the microwave system, the UV bulb is turned off into a stand-by position during shutdown periods. Start-up occurs quickly; therefore, in most applications, a shutter is not required with the microwave system.

The electrode system is a much simpler design than the microwave system. The simpler design has advantages in many applications. For instance, maintenance and troubleshooting are simple with electrode lamps. Spare-part costs are usually less for electrode lamp units than with microwave units. Electrical energy efficiency is higher with an electrode lamp compared to a microwave lamp. For systems where the lamps do not need to turn on and off on a regular basis, the electrode-lamp system energy cost is considerably less than for microwave lamps.

On projects where heat sensitivity is not an issue, the air-cooled electrode lamp is usually the most economical system. Where heat sensitivity is an issue or where the lamp needs to cycle on and off,

the microwave-powered system is a good choice. For ultra-sensitive heat substrates, such as thin plastic films or paper, water-cooled technology is usually best. There is considerable overlap of uses for each type of unit since each application's operating parameters can be different.

One of the important factors in deciding which lamp type to use is the formulation of the powder coating. The material supplier usually provides this information. Coatings can be intensity or dosage sensitive. Sometimes a material requires a high intensity at a specific dosage to get a proper cure. In cases like these, a high-powered lamp system with a very sharp focus should be chosen. The sharp focus provides high-peak intensity. Other coatings are formulated such that high intensity is not required. A lower, more even exposure of UV may be required if the product being cured is to be bathed in UV light. In this case, a flood pattern may be best. In either case, the total amount of UV-energy dosage is determined at formulation and should be specified by the coating supplier.

The intensity and dosage information helps determine the type of lamp needed. More information is required, however, to determine how the cure system is to be configured. Information on line speed, maximum part-envelope size, part-style mix on the line, part shapes, and substrate types also helps determine the lamp-system configuration. In many systems, lamps set up in fixed positions are adequate. However, with production lines that require coating of many different part shapes and sizes, the number of fixed lamps required would be so great that the system may become cost prohibitive. In these cases, UV lamps, mounted on automatic actuators, like reciprocators or robotics, can be more desirable.

For example, if there is a 5-ft (1.5-m) tall overall envelope size with many different part shapes, and if fixed lamps are used, two banks of lamps on each side of the conveyor would typically be used. One set would be angled downward to see the part's top surfaces and angled with conveyor travel to see the trailing edges. The second set would be angled upward to see the bottom surfaces and angled against the conveyor travel direction to see the leading edges. Another two sets of lamps would be required on

the opposite side of the conveyor to cure the backsides of the parts. A system of this design would consist of 24 10-in. (25.4-cm) lamps.

The same products could be cured using lamps mounted on a reciprocating lamp mover with 4–6 lamps mounted on a moving flight bar. With a reciprocator on each side of the conveyor, the number of lamps can be cut in half (or more) with this concept. So, not only is the initial investment considerably less than with fixed lamps, but the system is more flexible and costs less to operate because of less maintenance, fewer spare parts, and lower energy usage. The concept of curing 3D products matched with coating formulation technology enhancements has opened new possibilities for UV-curing applications.

CONCLUSION

The information presented in this chapter should provide a better understanding of UV-curing components and methodologies, resulting in a better understanding of UV-curing equipment and application techniques to maximize its potential. There is no substitution for actual testing in a production-like environment. Many UV-equipment suppliers have testing laboratories available to test and demonstrate UV-system capabilities and limitations. These labs allow a user an opportunity to gather needed data to compare UV applications to other technologies. In these labs, the feasibility of using UV-curable material can be determined before an investment is made in the equipment necessary to use the technology.



Appendix A: Powder Coating Test

PART 1: POWDER KNOWLEDGE—CHEMISTRIES AND PROPERTIES

1. Name at least two advantages epoxies hold over other chemistries.
2. Name at least two advantages polyester triglycidyl isocyanurate (TGIC) has over polyester urethane.
3. Name one major disadvantage of TGIC compared to urethane (other than price).
4. What chemistries do not have a curing agent in the formulation?
5. What does gel time indicate?
6. What does plate flow indicate?
7. During extrusion, what kind of reactions take place?
8. After UV degradation takes place, are there other physical properties affected?

PART 2: EQUIPMENT KNOWLEDGE

1. Name two functions of a powder booth.
2. Name the two main functions of an environmental room.

3. How are parts evaluated to determine if they are free of oil, grease, and smut?
4. What is the main function of a sieve in a powder system?
5. What type of powder-charging system produces a positive charge? Why?
6. What type of gun tip is recommended for a large flat surface?
7. What gun setting needs to be changed for recoating parts?
8. What does the atomizing air (or dosing air) knob control?
9. What is the disadvantage of over-fluidizing powder?
10. What causes reclaim powder to be smaller in average particle size compared to virgin material?
11. Define the following terms:
 - A. back ionization
 - B. impact fusion
 - C. Faraday Cage Effect

PART 3: TROUBLESHOOTING

1. If the powder is not wrapping around the part, what possible problems could this indicate?
2. Name three possible causes of a powder coating blistering and bubbling up.
3. If cured powder exhibits lower gloss than is standard, what could the possible causes be?
4. If cured powder exhibits a rougher surface than is standard (under the same substrate), what could be the possible causes?
5. If there is a question of the quality of pretreatment (adhesion, impact, or bubbling), how could you verify this condition in the field?
6. Name at least three possible causes of powder not accepting a charge.
7. How could you roughly estimate if a phosphate coating is too heavy?
8. In the field, how would you evaluate the quality of compressed air?
9. What screen size is recommended for conditioning of a smooth powder?

10. What is the solvent rub test most dependent on: clean parts or adequate cure?

PART 4: PRETREATMENT QUESTIONS

1. What is pretreatment?
2. What is a substrate?
3. What is a surface profile?
4. What is the best surface to paint over?
 - A. oxide
 - B. bromide
 - C. phosphate
 - D. raw steel
5. Describe the difference between steel and aluminum in the pretreatment phase.
6. What is a conversion coating?
7. How is oxide removed?
8. Is painting over oxide appropriate?
9. Describe the differences between sandblasting and pretreatment.
10. Describe the functional differences between a three- and five-stage-washer system.
11. What is a wetting agent?
12. Name five areas on the washer that need attention when daily checks are made.
13. What is the formula to determine the initial charge of a tank?
14. Define base versus acid. Be specific.
15. What is the formula to determine washer-zone time?
16. What are the functions of a rinse stage?
17. What is impingement?
18. What is pH?
19. What is RO water?
20. What is DI water?
21. What is TDS?

- 22. What does measuring conductivity provide?
- 23. Why is counterflowing used?
- 24. What is a halo?
- 25. What controls effective rinsing?
- 26. What is dragout?
- 27. What is bath life?
 - A. time between initial tank charge and tank disposal
 - B. time between start-up and shutdown
 - C. level determining how clean part gets
 - D. how long part is being cleaned
- 28. What is neutralization?
- 29. What is an eductor system?
- 30. How do you detect proper cleaning?
- 31. What is the purpose of the titrate process?
- 32. What is a concentration level?
 - A. intensity of operator
 - B. height of water or chemical level
 - C. tool that measures incline of tank
 - D. percentage of chemical in tank

Answers

PART 1: POWDER KNOWLEDGE—CHEMISTRIES AND PROPERTIES

1. Better chemical resistance, a wider range of coating hardness, chemically controlled gloss, and excellent corrosion resistance.
2. Higher film build up, no E-Cap, and low-cure temperatures.
3. More orange peel, and difficult to get low-gloss finishes.
4. Epoxy-polyester powders.
5. Level of reactivity of powder.
6. Ability of powder to flow and level off.
7. None. Powder-coating manufacturers do not make new polymers, only homogeneous mixes of all ingredients present in a powder formula.
8. No.

PART 2: EQUIPMENT KNOWLEDGE

1. To contain and reclaim powder.
2. Maintain proper ambient conditions (temperature and humidity) and keep foreign particles from the plant out of the booth.

3. With the white-towel test.
4. To break up agglomerations of powder particles and to remove fibers collected during reclaim.
5. A tribocharging system. Powder particles lose electrons that are picked up by the gun's inside tube.
6. A wide conical deflector or fan tip.
7. Lower kV.
8. The velocity at which the powder leaves the gun.
9. It may cause surging and spitting.
10. Cartridge-type reclaim systems concentrate the amount of fines in the reclaimed powder. Larger particles pick up a proportional charge to their mass and stick easier to the part. Smaller particles pick up less charge and fall off of the part, eventually ending up in the reclaim hopper.
11. A. Streamers that form due to the high flow of electrons and ions traveling through the layer of a powder-coated surface. The principal is identical (but traveling in the opposite direction) to that of corona ionization generated by the corona gun.
B. The buildup of powder particles in sharp hose bends, inside pumps, or at the tip of guns due to friction, heat, and humidity.
C. Part shape surrounded by grounded metal (in the recessed area) where electrostatically charged particles do not penetrate easily, due to better attraction to the outside surface of the recess.

PART 3: TROUBLESHOOTING

1. Poor ground, dirty hooks, or poor kV output.
2. Excess phosphate coating, water/moisture on parts, or dirty or rusted parts.
3. Excessive cure temperatures, or contaminated or incompatible powders.
4. Powder is B-staged or contaminated, back ionization has occurred during application, and powder is too coarse.

5. By running a side-by-side test with a B-1000 panel.
6. Powder is too fine, low kV output, poor ground, or broken electrode.
7. By seeing if the conversion coating leaves too much of a powdery film.
8. By blowing with an air nozzle on a clean white towel for about 60 seconds and seeing if the towel gets stained.
9. Between 60–100 mesh.
10. Adequate cure.

PART 4: PRETREATMENT

1. Pretreatment is the process of chemically cleaning and etching a substrate (part) prior to coating it, to remove surface tension, soils, and contaminants.
2. The substrate is the type of material to be pretreated (such as steel or aluminum).
3. The actual surface area to be coated; has a definite surface pattern.
4. D. raw steel
5. Steel substrates accept a conversion coating; aluminum will not (excluding chromes). Aluminum can only be cleaned and etched.
6. As the acid attacks the surface of the steel, pickling of the metal occurs, and phosphatizing is applied. Either iron or zinc phosphate covers the surface area.
7. Generally, oxides must be abraded or ground off the substrate.
8. No. Painting over oxide is never a viable alternative.
9. Sandblasting can rid the part of oxide, but may change the surface profile. Sandblasting is not always uniform. Chemical pretreatment will give increased salt fog results.
10. A three-stage washer uses an acidic wash and phosphate in one combined stage. A five-stage washer has a specific alkaline wash with a separate acidic phosphate stage for superior pretreatment performance.

11. A wetting agent is the same as a surfactant in that it lifts soils off the substrate surface in an aqueous system. It can be introduced at a later time than the initial surfactant to aid in removal of stubborn soils.
12. Chemical concentration level; pH level; water level; TDS level; and temperature.
13. $\text{Width} = \text{length} = \text{fluid-level height} \times 7.5 = \text{the percentage of the concentration needed in the tank.}$
14. All liquids are acid, base, or somewhere in between. Anything less than 7.0 pH is acidic; anything over 7.0 pH is alkaline.
15. Measure feet between first and last riser in the stage; then divide that by the line speed. This provides the time in the washer.
16. Prior to applying chemicals, rinsing any residual contamination remaining on the part will help neutralize chemicals.
17. Impingement is the mechanism of water under high pressure hitting the part and manually removing soils.
18. The potential of hydrogen; also referred to as a solution's degree of acidity or alkalinity.
19. RO is short for reverse osmosis. The RO process removes alkalinity, but not carbon dioxide.
20. Deionized water. Resin removes everything including carbon dioxide.
21. TDS is total dissolved solids. It is measured by the amount of conductivity in the solution.
22. Measuring the conductivity provides an estimate of the TDS in the solution.
23. Counterflowing keeps water usage to a minimum. Counterflowing starts at a halo or last rinse stage and feeds the prior stage its water, rather than overflowing it to drain.
24. A halo is a riser set used to either keep parts wet between stages or rinse off any residual contamination with clean/pure water.
25. Water cleanliness.
26. Dragout is chemical or rinse waters brought from the prior stage to the next stage via drainage, cupping, or runoff.

27. A. time between initial tank charge and tank disposal.
28. Neutralization occurs when two chemicals mix and bring the pH level toward a more neutral pH.
29. Eductor systems agitate the washer-tank floor and keep soils suspended so they can be removed through a filter system.
30. A water-break-free test can be administered any time, but it is primarily done after the washer exit. The white-towel test is usually administered after the dry-off oven exit or cool-down tunnel.
31. To determine the concentration level of the tank.
32. D. percentage of chemical in tank.



Appendix B: Glossary

A

abrasive: Agent used for abrasive blast cleaning. Examples include sand, grit, steel shot, and glass beads.

adhesion: Bonding strength, or attraction, of coating to the surface where it is applied; the property that causes one material to stick to another.

aftercooler: Device for removing heat after compression is completed; one of the most effective ways to remove moisture from compressed air.

agglomerate: To gather into a ball, mass, or cluster.

airflow: Air speed typically measured in ft/min.

air knife: Mechanical device that uses a small amount of compressed air to pull in large volumes of surrounding air and produce a high-flow, high-velocity curtain or sheet of air.

airborne particles: Particles suspended in moving or stationary air.

air classifier: Powder-coating device used to classify particle size.

air lock: Device used for metering powder into a sieve.

air receivers: Tanks for discharged, compressed air, or gas that help eliminate pulsation in the discharge line.

ambient air: Air in the area surrounding the spray booth that may be filtered and/or environmentally conditioned.

anchor pattern: Profile of a part; usually attained by sand-blasting.

appearance: Visual measurement of a coating determined through gloss, DOI, or tension testing.

atomizing air: Air injected into a liquid or powder path to atomize it into a mist or cloud.

automatic zone: Area in a spray booth that uses automatic spray equipment to apply powder.

B

B-staging: Process describing powder-coating material that has been partially reacted or cured during manufacturing or storage.

back ionization: Condition occurring when excessive build-up of charged powder particles limits further powder from being deposited on the substrate.

blow-off: Removal of particulate and fibers from materials in preparation for powder application using compressed or high-volume, fan-driven air.

booth: Enclosed area that provides for the intake of fresh air and exhaust of contaminated air.

bulk blender: Device used in powder manufacturing to mix multiple baths of powder resulting in a homogeneous blend.

bulk density: Solid mass, per unit of volume.

C

capture air velocity: Average speed of air drawn through the booth opening.

capture air volume: Volume of air needed to capture oversprayed powder within a booth.

cartridge booth: Type of powder booth developed by Nordson Corporation that incorporates a cartridge filter system within the booth.

cartridge filters: Preassembled filter media that has been fluted, convoluted, and/or made in cylindrical or canister form.

chalking: Degradation or decomposition of paint film by gradual erosion of its binder; a loose powder forms on the surface and is easily detectable by wiping the film.

chipper: Device used to flake extrudate of powder or plastic materials and put in a form conducive to grinding.

cloud-chamber technique: Method of moving a charged or uncharged object through charged or uncharged cloud of powder in an enclosed chamber.

coating: Surface covering; paint, barrier, or film applied in thin layer for protection and decorative purposes.

collection hopper: Means of containing oversprayed powder for recycling or disposal.

compatibility: Capable of being mixed easily without causing surface or chemical defects; may also pertain to the adherence ability of dissimilar coatings to each other, or of a coating to a substrate.

compliance coating: Coating that meets all air, water, and waste disposal regulations.

contaminants: Foreign material such as dirt or trash detected in cured powder coating.

controlled environment: When parameters of surroundings such as temperature, pressure, humidity, and containment levels are monitored within specified limits.

corona charge: Process of inducing a static electric charge on powder particles by passing them through an electrostatic field generated by a high-voltage device.

cratering: Small depressions in paint film that may or may not expose the underlying surface; can be caused by gassing, incompatibility, or silicones.

cross draft: Term used in reference to paint booth configuration. Air movement in a sideways or horizontal direction from supply to exhaust.

cross hatch: A test to demonstrate adhesion characteristics of a paint or powder-coated surface, performed by scribing a cross-hatch pattern at specified intervals and applying and pulling area with tape.

cross-linking: Place where chemicals unite to form films.

cure: Process when paint is converted from liquid to solid state; to change physical properties of a material through chemical reaction by means of condensation, polymerization, or vulcanization.

cure agent: Hardener or cross-linking agent.

cure-end point: The point, either during or following the cure schedule, at which powder-coating film is determined to have developed specified properties.

cure schedule: Time and temperature relationship required to properly cross-link powder coating.

cut-through resistance: Resistance of film to penetration resulting from the combined application of sharp edges, heat, and pressure.

cyclone collector: Particle separator that removes powder-paint particles by throwing them to the outside of a cone-shaped container where they fall down the side and are collected at the bottom of the container.

D

deionized water: Water containing no ions.

delivery: Process of moving powder-coating material through application equipment to the end product.

dip coating: Coating of a part by immersion in a filled tank and then withdrawing it.

dirt: An undesirable inclusion in paint film caused by disturbances in the paint process.

dispersion: To break big particles into small particles and suspend in water for removal by rinsing.

distinctness of image (DOI): Measurement of clarity of light reflected off of a painted surface.

downdraft booth: Spray booth where air moves from ceiling to floor.

dry-blend agent: Dopant; material generally blended into a coating powder to enhance dry-flow or tribocharge characteristics.

dry blending: Process where powder-coat manufacturing materials are blended together in dry form without melting.

E

edge coverage: Powder coat's ability to form continuous film over sharp edges, corners, and angles.

electrostatic deposition: Technique of moving and charging powder so it is deposited onto a grounded surface.

electrostatic discharge: Transfer of electrostatic charge between bodies with different electrostatic potentials.

electrostatic-fluid bed: Fluid bed equipped with grid to charge powder.

electrostatic rejection: Condition of excessive buildup of charged-powder particles limiting further powder from being deposited on substrate; may occur during electrostatic applications and can reverse the charge of the surface layer of powder particles.

electrostatic spraying: System of applying paint where atomized-paint droplets or powder particles are given an electrical surface charge that results in attraction to the grounded workpiece.

etching: Surface preparation of metal by chemical process; removal of a layer of the base metal.

extended surface filters: Filters with a greater media area than filter-face area; characterized by type of media used and configuration, including pleated panels, pockets, bags, rigid cells, and pleated cartridges, and generally manufactured from such materials as air or wet-laid glass fibers, cotton synthetics, or synthetic polymers.

extrudate: Molten plastic or powder coating that exits extruder.

extruder: Machine used to make powder coatings by melt mixing plastic blend; utilizes heat and mechanical kneading to achieve homogeneous mixture.

F

fading: Reduction in brightness or color; gradual loss of color due to pigment degradation caused by ultraviolet radiation in sunlight.

Faraday Cage Effect: Phenomenon of charged particles prevented from entering recessed areas due to curvature of electric force lines on nearest grounded surface.

filiform corrosion: Corrosion resembling a thread-like formation; usually caused by poor substrate cleaning or rinsing.

filler: Ingredient in making of powder such as an extender, bulk-ing agent, or inert pigment.

film integrity: Degree of continuity of film.

film thickness: Depth of an applied coating, expressed in mils (μm), such as 1/1,000 in. (25.4 μm).

film thickness gage: Device for measuring film thickness on wet or powder films.

finer: Extremely fine part of powder coating usually considered to be waste; finer have poor charging capabilities (6 μin . [15 μm] or finer).

first run: Refers to parts that have gone through the complete paint process once, starting from a previously unpainted state, and meeting final acceptance criteria.

fish-eye: Small round depressions in paint film that may or may not expose the underlying surface.

flash rusting: Very thin coating of rust or oxide occurring within minutes to hours after applying a wet film of certain water-borne coatings.

flat-spray nozzle: Powder-gun tip used to produce a fan-spray pattern.

flocking: Spraying with a special gun of fine fibers, along with a liquid paint binder, which results in a cloth-like finish; also a deposition method of applying powder by spray to a substrate heated above melting point.

fluidized bed coating: Process for applying organic coatings when pressurized air flows through a diffuser plate into a chamber containing finely powdered coating material. The air causes the powder to become suspended (fluidized), resembling a boiling liquid. Heated parts are then immersed in fluidized powder, where coating is simultaneously applied and fused.

friable: Easily crumbled or pulverized; denotes ease with which a coating or resin can be ground into a powder.

fusion: Melt and flow of individual powder particles to form continuous film.

G

gassing: Air or gas that escapes from the subsurface and causes blisters, bubbles, or small holes in coating; frequently occurs with zinc or aluminum castings or galvanized steel and is commonly referred to as out-gassing.

gel time: Interval required at a given temperature for powder to be transformed from dry-solid to gel-like state.

glass-plate flow: Measurement of flow-out, or viscosity, when powder is in a molten state.

gloss: Finishing; one of several appearance attributes that produce a sensation of brightness or luster of a smooth polished surface. Degree that a surface reflects light.

gloss retention: Ability of film to retain original gloss.

gravelometer: Device used to test the life of a part by exposing it to air-blown gravel; extent of failure is determined by counting the number of chips and size ranges in film coating.

grind: Size of powder and pigment particles in paint dispersion.

grinder: Device used to crush or pulverize plastics or solid coatings into powder form; known also as micronizer or pulverizer.

H

hardness: Ability of dry-paint film to resist indentation.

HEPA filter: High-efficiency particulate air filter to separate particles.

hiding: Film thickness of paint that will completely hide underlying surface.

hiding power: Ability of powder to mask color or pattern of surface. Hiding power is usually expressed as ft^2/gal or m^2/L .

high-film build: Producing thick films per coat (see hiding).

holiday: Pinholes, skips, discontinuities, or voids.

holiday detector: Tool used to detect holidays.

humidity: Measure of the amount of moisture in the air. The drying time of water-based paint is greatly affected by the amount of humidity present.

hybrid: Epoxy-modified polyester or acrylic-thermoset powder. Hybrids generally have good overbake resistance and good application properties.

I

impact fusion: Tendency of finely divided powders to combine with other particles via bombardment or friction during an application process and form a hard, crusty buildup.

incompatibility: Inability to mix or adhere to another material without negative surface appearances, such as loss of gloss or, in extreme cases, craters.

infrared oven: Electric or gas-fueled oven using a series of lights or reflectors emitting infrared energy to the part.

indexing: Manual or automatic starting, stopping, or rotating of a carrier.

intercoolers: Devices for removing heat in air after compression is complete.

intercoat adhesion: Powder's ability to adhere to a previously applied coating.

iron phosphate coating: Chemical deposition of phosphate on steel.

isocyanate resins: Urethane resin and curing agents.

L

leveling: Ability of film to flow out to a smooth, uniform thickness.

low-film build: Coating where film build is too thin.

lower-explosion limit (LEL): Point of concentration of a compound in air below which a flame will not propagate if the mixture is ignited.

M

make-up air: Fresh air drawn into the building from an outside source.

manometer: Pressure-activated indicator that monitors airflow.

manual zone: Area in powder-spray booth where people apply coatings.

masking (material): Application of high-temperature tape and/or other material to protect certain areas of the product to prevent it from being coated with powder.

material safety data sheet (MSDS): Information supplied by the manufacturer listing all hazardous ingredients, physical and health hazards, first-aid procedures, and protective equipment.

melt-blend powder: Process of mixing all ingredients in a molten state. Product is then cooled and ground to proper particle size, resulting in uniform composition of each particle.

melt mixing: Process for manufacturing powder coatings involving continuous compounding of pigments, fillers, catalysts, and resins at elevated temperatures.

melt point: Temperature at which finely divided powder begins to melt and flow.

micron/mils: Common unit of measurement of coating thickness. $25\text{ }\mu\text{m}$ (microns or micrometers) = 1 mil (0.001 in.).

micronizer: Another term for grinder. To micronize is to reduce to particles that are a few microns in diameter.

mil: Measurement of paint-film thickness equal to 1/1,000 of an inch (0.001 in.) or $25.4\text{ }\mu\text{m}$ in metric terms.

minimum explosive limit: Lowest point that can be ignited by a sufficient heat source for a range of concentrations of organic particles suspended in air.

moisture separators: Devices for collecting and removing moisture precipitated from air during the cooling process.

molecule: Smallest particle of substance that can exist without losing its chemical form.

N

Non-electrostatic deposition: Technique of depositing powder onto substrate that may be heated above the melting point of the powder material.

nonferrous: Containing no iron.

nylon: Thermoplastic powder coating.

O

opacity: Ability of powder to cover or hide an area such as a previous coating.

orange peel: Irregularity in the surface of coating film resulting from an inability of the film to level out; characteristically appears as an uneven or a rough surface, but usually feels smooth to the touch.

organic: Substance containing carbon compounds.

overbake: Result of curing coating film at too high a combination of time and temperature causing wavy irregularity in surface of paint film.

overspray: Portion of powder that does not contact and adhere to the part during the coating process.

P

paint-shop clean room: Portion of paint shop that contains tightest controls and restrictions on dirt and is generally isolated by various methods.

particle size: Average diameter of object having irregular boundaries; determined through various test methods.

passivation: Conversion of metal surface to less reactive state to reduce corrosion rate of metal surface.

pencil hardness: Measurement of hardness or cure of paint film.

phosphatize: Formation of thin, inert phosphate coating on surface.

pickling: Use of chemical solution to prepare surface for coating or bonding by dissolving away surface oxides and other impurities.

pigment: Finely ground powders in paint that give it color.

pinholing: Formation of small holes through entire thickness of coating.

plate flow: Distance powder coating flows in molten state prior to gel.

porosity: Degree of integrity or continuity.

post curing: Extended heating of part after powder-coat cure cycle ends.

pourability: Ability of dry powder to flow uniformly or continuously at a steady rate from a container.

powder coatings: Powder coatings are protective, decorative, or both. Formed by the application of coating powder to a substrate and fused into continuous film with application of heat or radiant energy.

power wash: Multistage cleaning and conditioning machine or structure to transport material using some form of conveyor system.

preheat: Heating a part prior to application of coating.

pretreatment: Chemical cleaning and etching prior to powder application.

profile: Surface contour; usually used as a blasting term.

profile depth: Average distance between top of peaks and bottom of valleys of a surface.

R

radiation cure: Curing a coating by exposing it to electromagnetic waves or particles such as infrared, ultraviolet, or electron.

reclaim: Process to recycle unused powder.

reclaimed powder: Powder that has been oversprayed and recovered.

recoat: Salvaging a part through refinishing by sanding and spraying it.

recovery: Process of removing undeposited powder from air prior to circulating it through the delivery system.

recycled powder: Powder that has been oversprayed, collected, and conditioned for reuse.

reflectance: Degree of reflected light.

repelling: Condition during electrostatic application of powder where excessive buildup of charged powder particles limit further powder deposits on the substrate; can reverse electrical charge of the surface layer of powder particles (also referred to as electrostatic rejection or back ionization).

resin: Substance of natural or synthetic origin used as binder for powder. Most resins are polymers.

resistivity: Measurement of a liquid's ability to conduct electricity.

respirator: Safe breathing mask.

reverse osmosis (RO): Method of removing ions from water to make purer water.

rework: Parts not meeting final acceptance criteria that must go through paint system again; also refers to process of sanding or otherwise removing defects from a painted part in preparation for repainting.

S

salt-spray test: Corrosion test performed in a humidity chamber.

sandblast: Blast cleaning using an abrasive.

scale: Rust occurring in thin layers, commonly found on hot-rolled steel.

screen-mesh size: Openings per square inch of a screen using standard-size wire.

seeding: Agglomeration of pigment- or resin-forming particles in paint that can form when material overheats during the extrusion process.

shelf life: Maximum time material may be stored and still remain in usable condition.

sieve: Powder-particle classifier that uses wire mesh of various sizes to screen out oversize powder particles, foreign material, or dirt.

silhouette: Partition wall to reduce size of opening of entrance or exit from paint booth and pretreatment tunnels.

sintering: Tendency of some powder-coating materials to agglomerate during storage.

solution: Mixture formed when one material is dissolved into a liquid.

solvent rub (MEK test): Determines solvent resistance or cure of paint film by rubbing dampened solvent stick over surface and evaluating the appearance of surface.

spray/reclaim booth: Specially designed enclosure where coating powders are introduced, contained, and recovered during coating process.

storage stability: Ability of powder coatings to maintain uniform physical and chemical properties after being subjected to manufacturers' specified storage conditions.

substrate: Base material (such as steel, aluminum, or zinc) of product to be painted.

surface appearance: Generally refers to smoothness and gloss of powder-coating films and presence or degree of surface defects.

surface defects: Flaws in the surface of a coated part.

T

tack-off: Process of using tack cloth to remove particulate and fibers from a surface to be painted.

tack cloth (or tack rag): Wiping cloth usually treated with a nondrying tackifier to pick up particulate and fibers from a surface.

tension: Measurement of clarity of light reflected off a painted surface.

TGIC: Triglycidyl isocyanurate.

thermoplastics: Powder coating that repeatedly melts when subjected to heat and solidifies when cooled.

thermosetting: Powder coating designed to undergo irreversible chemical change during the cure schedule.

transfer efficiency: Ratio of powder deposited compared to the amount directed at the part to be coated.

transportability: Powder coating's ability to be carried in an air stream and pass through tubing and ducts.

tribocharging: Creating static charge on powder particles with friction against nonconductive material.

Tukon: Measurement of hardness or cure of paint.

V

venturi: Constricted throat in the air passage of powder pumps used to determine velocity of powder.

virgin powder: Unsprayed, unused powder, as opposed to sprayed or reclaimed.

volatile organic compound (VOC): Quantity expressed as the weight percent of powder lost under specified conditions of temperature and time.

W

washer crystal: Particles caused by crystallization of minerals, additives, cleaners, or chemicals found in the water of power washers.

water spotting: Visual blemish that occurs on the surface in areas where water droplets have dried and left dissolved solids.

wrap: Characteristic of powder coatings in electrostatic application to seek out and adhere to parts.



Appendix C:

Metric Conversion Tables

Table B-1. Temperature

°F	°C	°F	°C	°F	°C
0	-17.8	110	43.3	310	154.4
5	-15.0	120	48.9	320	160.0
10	-12.2	130	54.4	330	165.6
15	-9.4	140	60.0	340	171.1
20	-6.7	150	65.6	350	176.7
25	-3.9	160	71.1	360	182.2
30	-1.1	170	76.7	370	187.8
35	1.7	180	82.2	380	193.3
40	4.4	190	87.8	390	198.9
45	7.2	200	93.3	400	204.4
50	10.0	210	98.9	410	210.0
55	12.8	220	104.4	420	215.6
60	15.6	230	110.0	430	221.1
65	18.3	240	115.6	440	226.7
70	21.1	250	121.1	450	232.2
75	23.9	260	126.7	460	237.8
80	26.7	270	132.2	470	243.3
85	29.4	280	137.8	480	248.9
90	32.2	290	143.3	490	254.4
95	35.0	300	148.9	500	260.0
100	37.8				

Table B-2. Inches to millimeters

in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
10	254.00	1	25.4	0.1	2.54	0.01	0.254	0.001	0.0254	0.0001	0.00254
20	508.00	2	50.8	0.2	5.08	0.02	0.508	0.002	0.0508	0.0002	0.00508
30	762.00	3	76.2	0.3	7.62	0.03	0.762	0.003	0.0762	0.0003	0.00762
40	1,016.00	4	101.6	0.4	10.16	0.04	1.016	0.004	0.1016	0.0004	0.01016
50	1,270.00	5	127.0	0.5	12.70	0.05	1.270	0.005	0.1270	0.0005	0.01270
60	1,524.00	6	152.4	0.6	15.24	0.06	1.524	0.006	0.1524	0.0006	0.01524
70	1,778.00	7	177.8	0.7	17.78	0.07	1.778	0.007	0.1778	0.0007	0.01778
80	2,032.00	8	203.2	0.8	20.32	0.08	2.032	0.008	0.2032	0.0008	0.02032
90	2,286.00	9	228.6	0.9	22.86	0.09	2.286	0.009	0.2286	0.0009	0.02286
100	2,540.00	10	254.0	1.0	25.40	0.10	2.540	0.010	0.2540	0.0010	0.02540

Table B-3. Gallons to liters

Gallons	Liters
1	3.79
2	7.57
3	11.36
4	15.14
5	18.93
6	22.71
7	26.50
8	30.28
9	34.07
10	37.85



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