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Norman R. Roobol is widely recognized for his expertise in industrial painting; he is the author of over 200 articles and other publications in this field. For 25 years he was a professor with General Motors Institute and he has assisted scores of U.S. and Canadian plants in the selection of painting equipment and processes and in the solving of painting problems. Dr. Roobol is the author of Industrial Finishing magazine's Painting Forum column. His highly successful book Painting Problems: Solved (Hitchcock, 1987) is now in its second printing.
Industrial Painting
Principles and Practices

Norman R. Roobol

Hitchcock Publishing Co.
Carol Stream, IL 60188
I have designed this book to be useful and practical rather than highly theoretical. It is a volume on industrial painting which provides information that will be of value on the plant floor. No knowledge of chemical theory is necessary to understand any section and everything is explained in a straightforward manner. Where it is instructive this author has included small amounts of basic science. This was done so readers can fully comprehend the principles involved and also to avoid a “do this – do that” style presentation. The book contains a wealth of information which will be instructive for everyone who is associated with painting; those brand new to paint and those veterans of many years painting experience can learn from it.

The chapter order in which topics are presented follows very closely that of my three-day Industrial Painting Processes course. That instructional painting seminar has been presented well over 150 times, both as a public offering and as private in-plant sessions. The actual course content has constantly been altered over the past twenty years. The methods and procedures of industrial painting operations undergo constant gradual shifts, but the topic order of this book is basically the same as the current course. This sequence has repeatedly been found to be best for maximizing the learning experience.

For many years I had been looking for a strong and accurate industrial painting textbook. Even after I realized that I would probably need to write it myself, the hope remained that someone else would go through the long and arduous task of putting together a book such as this. Yet when the need for a text finally forced me to begin this book it was often enjoyable despite the inevitable delays, frustrations, and difficulties. If this volume helps people to improve their paint quality and economy my goal will be achieved.

NORMAN R. ROOBOL
DEDICATION

This is for Joan, my wife and my life. It’s for my kids too, who show their love and support in so many ways. Thanks, you guys! Also for Louise Ezinga, the most loving and loved mother-in-law imaginable.

Many persons assisted me in writing this book. Thanks go out to each of them, especially to Joe Schrantz for editing my manuscript.

I am always eager to hear from anyone who has comments on any part of it. All suggestions for improvement will be incorporated into future editions of this work. Contact me at the address below.

"Cor Meum Tibi Oﬀero Domine, Prompte Et Sincere"

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For the proper bonding of paint to a material’s surface, the surface to be painted must be free of contamination. No foreign matter, dirt, or other impurities should remain between the surface and the paint, because foreign matter can only detract from a paint’s appearance and bonding integrity. Clean surfaces are required for painting, regardless of the type of material that is to be painted. Surfaces to be painted fall into five general categories of materials: cloth, paper, wood, plastic and metal.

Cloth and paper are typically manufactured in long sheets that are wound on rolls. They are clean as manufactured and generally need not be cleaned before being painted. Wood, plastic and metal items are manufactured in all sorts of sizes, styles and configurations. The paint applicator almost always needs to clean metal items and often plastic items before painting.

Wood surface “cleaning” often involves a mechanical smoothing such as sanding with fine sandpaper and wiping with a clean, lint-free cloth. Using fluids to clean wood is usually avoided; fluids such as water or solvents can raise the wood’s grain, and finish sanding is then again necessary before a coating can be applied.

Cleaning plastic surfaces usually involves a simple mild washing, rinsing and drying. The wash solution should usually contain the mildest of detergents. Solvent cleaning of plastics, when required, demands great care; solvents can damage plastics by interfering with their molecular structure. The result can be swelling, crazing or cracking of the item.
Metal Surface Cleaning

Methods for cleaning metal surfaces before painting vary with the type of metal. Cleaning metal becomes much more involved than cleaning wood or plastic, because metal fabricating processes typically use various oils to lubricate the part as it is processed through presses, brakes, roll formers and other machines. The fabricated part consequently is often oil-soaked and covered with metal powder, filings and chips. The contaminants might even include glue and weld spatter. In addition, some fabricated metals stored outdoors before painting can collect deposits of oxides. Even when the item remains indoors, iron will form iron oxide (rust); zinc will collect zinc oxide (white rust); and aluminum will develop aluminum oxide. These oxides should be removed or treated before painting.

Most manufactured metal surfaces to be painted fall into one of the following categories: ferrous (containing iron), zinc (typically galvanized) and aluminum. All of these have optimum cleaning chemicals; the cleaning procedures, however, are practically identical. These procedures can include:

- Mechanical cleaning
- Solvent cleaning
- Aqueous cleaning
- Acid cleaning
- Alkaline cleaning

The optimum cleaning method for a particular metal part depends on the type of contaminants to be removed. Methods for cleaning the different types of metal, e.g., steel as compared to zinc, may also vary.

Mechanical Cleaning

Mechanical cleaning may include something as ordinary as wiping dust from the surface with a clean cloth. When firmly attached metal scale or heavy rust must be removed, vigorous cleaning methods are required. Abrasive removal using a sanding belt or disk or manually applied abrasive pad can be effective. Equally beneficial may be the use of a wire brush or wheel to remove tenaciously held rust. When very large areas are to be cleaned, it often is efficient to use sand or grit blasting with grit suspended in a high-pressure air or water blast. The grits used in this technique can include sand, steel shot, glass beads, aluminum oxides and soft-cutting organic materials such as ground walnut hulls or ground corncobs. Rather than being carried by an air or water “blast,” grit materials may also be vigorously “hurled” from a rotating wheel or moving belt at the object to be cleaned. With grit cleaning or blasting, care must be exercised to avoid leaving grit particles embedded in the surface as these can cause poor paint adhesion and possible early corrosion under the paint film. When recirculated grit is employed, provision
Cleaning the Surface

should be made for separating and removing accumulated debris.

Mechanical cleaning may be coupled with liquid cleaners using cushioned plastic wool pads, which have the advantage of not loading up and becoming “blinded” and dirt-embedded. Like sanding media, the pads are available in a range of physical sizes and grit sizes from coarse to fine.

**Solvent Cleaning**

Because oils and greases are not reliably removed by mechanical action, suitable solvents provide invariably more effective methods of removal. Solvent cleaning by spray, vapor or dip may be coupled with wiping with a solvent-saturated sponge or cloth. The wiping material and any solvents used in spray, dip or wiping must be clean or else dirt, oil or grease will be left on the part being cleaned. Dip tanks of clean solvent soon become dirty from removed contaminants. The resulting problem with dip-type solvent cleaning, then, is that parts may be only partially cleaned. Solvent spray is not commonly used for cleaning, but when it is, recontamination of parts with dirty solvent will also occur unless parts are sprayed only with fresh solvent. Continuous distillation can ensure that the used solvent remains clean. The expense of continuous distillation, however, is not practical unless warranted by a sufficiently high production volume.

Solvent cleaning needs to be done in a confined space to keep vapors away from people and other processes in the vicinity, and flammable solvents should never be used. A method of solvent cleaning has been devised that efficiently contains the solvent vapors and, as a bonus, continuously filters out removed contaminants. This method is known as “vapor degreasing.”

The basic components of the type of vapor degreaser shown in Figure 1-1 are a tank, source of heat, condensing coils and accompanying refrigeration components, water separator, solvent recirculation pump, filter and a supply of solvent. The heat source maintains the solvent at its boiling temperature, sending vapor upward to the refrigerated condensing coils, where the vapor condenses and flows back to the solvent supply. The water separator catches moisture collecting on the condensing coils, keeping the water out of the solvent. The condensing coils are located a precise distance—called the “freeboard”—from the top of the tank. The freeboard length is calculated to prevent solvent vapor escape from the tank. Vapor degreasing tanks may range in size from as small as about five gallons to over 20,000 gallons.

Common solvents (and their boiling temperatures) for vapor degreasing are methylene chloride (104°F), 1,1,1-trichloroethane (165°F), trichloroethylene (188°F) and perchloroethylene (250°F). The solvent choice is usually determined by the material being processed and the type of contaminant to be removed. Perchloroethylene, with its high boiling temperature, might be chosen to clean a
sturdy material, such as a steel casting that is contaminated with waxes and tar. Methylene chloride, with its low boiling temperature, might be selected to clean a temperature-sensitive part covered with only light soils.

Many traditional chemical solvents are no longer acceptable for use or are recommended with caution, to be used only in strictly controlled circumstances. Carbon tetrachloride, for example, once a common cleaning agent, has been found to be very carcinogenic and is no longer acceptable for use. In addition, halogenated hydrocarbons may be toxic and/or can cause environmental damage.

A part is usually immersed into a vapor degreaser only as far as the vapor zone. The hot solvent vapor contacting the ambient (room) temperature part will condense and flow off the part, thus carrying away oils and dirt. The condensing action will continue until the temperature of the part reaches that of the solvent vapor. Withdrawing the part slowly through the freeboard area allows the solvent to evaporate and return to the vapor zone. The part entry/exit movement rate must be controlled carefully to minimize vapor dragout.

If parts are especially dirty, sometimes they are sprayed with solvent in the vapor zone, either with a manual wand or automatic nozzles. The principle of operation of such a vapor degreaser remains the same as when no solvent spray is employed. Occasionally, extra-dirty parts are dipped to the bottom of the vapor degreaser directly into the boiling solvent. After a soaking period, they are removed and dipped in a fresh solvent supply in order to cool them to room temperature. The parts are then usually put into the vapor zone for a final conventional vapor degreaser cleaning.
An important aspect of vapor degreaser cleaning is that only nonflammable solvents can safely be used. Flammable materials would constitute a totally unacceptable fire hazard. When vapor degreasing is being done—and whenever halogenated solvents are used—care must be taken to keep the vapors from being drawn into direct-fired ovens. Any vapors created when chlorinated hydrocarbons come into contact with flames form corrosive gases such as hydrochloric acid vapor. These acid vapors can wrinkle the finish on freshly painted parts in an oven; and, the acid vapors present a potential health hazard to persons who are sensitive to this irritant.

Another possibility in vapor degreasing is that ultrasonics can be included to speed the dislodging of stubborn dirt during liquid solvent precleaning—the preliminary cleaning intended to dislodge heavy dirt. In ultrasonic cleaning, intense vibrations just above the audible frequency level are generated and transferred to mechanical energy through a transducer to agitate solvent in the vicinity of the part being cleaned. The ultrasonic energy helps to break up soil and get solvent and detergent under soil and grease. The cost of running ultrasonic transducers is often appreciable but may be cost-effective in helping to remove tenacious soils. Ultrasound is not commonly used as a prepaint cleaning operation, however.

**Aqueous Cleaning**

Aqueous cleaning systems—water plus detergent and acidic or alkaline chemicals—are the most popular in industrial finishing. Two main advantages of these systems are the absence of solvent fumes and the ready adaptability to practically every cleaning requirement.

The basic types of aqueous cleaning are spray-impingement and dip. Low-volume operations commonly use manual spray or dip; high-volume manufacturing generally uses automatic spray or dip. The choice of spray, dip or a combination of spray and dip is determined by the nature of the product to be cleaned.

Large, bulky, relatively low-volume items—such as farm tractors, for example—are often cleaned manually. Most high production items, such as car bodies, are cleaned automatically. The choice of dip cleaning might be made by a manufacturer for a complex-shaped product that requires cleaning in deep, hard-to-reach areas. Many automotive body cleaning systems incorporate both spray and dip: spray impingement to clean visible surfaces, and dip to penetrate hard-to-reach areas.

Manual spray is usually accomplished with a spray nozzle attached to the end of a long wand as shown in Figure 1-2. The wand permits the operator to stay a safe distance from the nozzle in order to avoid getting sprayed. High fluid pressures are usually used in manual spray cleaning. In contrast, automatic spray cleaning
systems incorporate fixed plumbing components including headers, risers and nozzles. Headers, constructed of large-diameter piping, carry the cleaning solution to the risers, which are made of small-diameter piping. The risers are usually shaped in a loop containing horizontal and vertical members, and the part to be cleaned passes through the loop. Nozzles attached to the risers—perhaps every 6 in. or so apart—provide a curtain of spray for the part to be cleaned to pass through. Numerous riser loops can be used; some systems have riser-loops spaced about a foot apart through the length of the cleaner zone.

Parts are usually conveyed through the risers hanging from an overhead conveyor as shown in Figure 1-3. Various configurations of the conveyor and risers are possible to minimize moisture reaching the conveyor; moisture contributes to high conveyor maintenance and may allow drippage of conveyor soils onto the parts being cleaned.

The cleaner portion is usually the first stage of an automatic spray washer. In addition to the riser-nozzle loops, automatic spray washers incorporate external reservoir tanks that contain the chemical solutions (Figure 1-4) being sprayed onto the parts to be cleaned. The reservoir tanks provide a convenient means of replenishing the chemical solutions as they become depleted with use.
Figure 1-3. Overhead Conveyor Carrying Parts Through an Automatic Spray Washer

Figure 1-4. Automatic Spray Washer Boxlike Protrusions (right) Contain Chemical Solutions and Rinses
Acid Cleaning

Rust, scale and oxides can be removed rapidly by using an acid pickling (brightening) solution to etch the top surface of the metal that contains the soil. The acid may contain an inhibitor to slow the etching action to a desired rate to suit the part being cleaned and the type of soil to be removed. Both hydrochloric and sulfuric acid can be used for steel, and aluminum is frequently cleaned with nitric acid solutions. Hydrogen embrittlement occurs readily in acid cleaning because hydrogen gas is produced that can penetrate deep into the metal, reducing tensile strength.

Alkaline Cleaning

Strong aqueous alkali can be used to remove oxides from steel, but zinc, magnesium and aluminum react vigorously with highly alkaline solutions. Unlike acidic treatments, however, alkaline solutions do not cause hydrogen embrittlement. Relatively mild alkaline detergent solutions are used to clean many types of metal products. In general the stronger the alkali, the faster the soil is removed and the more thoroughly the soil is dispersed in the cleaning solution. Throughout this cleaning process only enough alkalinity is introduced for removal and dispersion; elevated alkalinity results in poor rinsability, and thorough rinsing of cleaners is crucial for good painting.

In addition to a caustic “builder,” the source of the alkalinity, a typical cleaner formulation contains synthetic detergent or soap. These agents often have additives to minimize foaming and may also contain a sequestering or chelating agent to reduce water hardness. Occasionally alcohols and glycol ether solvents are added to speed cleaning. As a rule cleaning effectiveness is increased with nonionic detergents compared with the more frequently used anionic detergents. The nonionics are more expensive, but they work in relatively low temperatures and are low-foaming.

Cleaning can also be improved using a double wash system, either wash-rinse-wash-rinse or wash-wash-rinse-rinse. In the first system, the first wash removes the brunt of the soil, and the second can be replenished and overflowed to supply the first. Because of the necessity for thorough rinsing, the second system might be a better procedure. In both systems, the quality of the rinse water is important.

Immersion (dip) cleaning reaches all surfaces, but since it does not clean as fast as a spray process, it often requires concentrated cleaners. In some cases silicated immersion cleaners are used. Although these clean fast, they may passivate (deactivate) the surface and thus cause slower chromating and produce unsightly streaking that in some cases is visible. Silicated cleaners can inhibit excessive alkali attack on aluminum and zinc when concentrated solutions must be employed to clean heavily soiled parts.
Most aqueous cleaners are operated at 125 to 160°F. Cleaners of all types work better hot than cold; oil and grease are mobile when hot. Heating the cleaner and rinse stages raises the temperature of the metal to be compatible with the temperature of phosphating solutions that often follow cleaning. The first cleaning stage is normally operated at a high temperature to facilitate cleaning and heating of the metal, and the remaining stages are gradually lowered in temperature to that of the following phosphate or chromate stage.

**Cleaners for Aluminum**

Aluminum can be cleaned with various chemicals; the configuration of the parts, the alloy composition and the desired results influence cleaner selection. Cleaners used on aluminum include:
- Silicated alkalines
- Nonsilicated alkalines
- Organic acids
- Acid-etchants
- Alkaline-etchants

**Silicated alkaline cleaners.** Silicated alkaline cleaners, known also as nonetching cleaners, are used at a pH (acid/alkali rating) of 11 to 13 (see Figure 1-5) and can remove grease and waxy soils.

**Nonsilicated alkaline cleaners.** Nonsilicated alkaline cleaners operate at a pH of 8 to 10 and are mostly used prior to a caustic etch before chromating or anodizing. Nonsilicated cleaners are excellent products and present little problem of cleaning agents drying on parts. Although they are considered to be nonetching, nonsilicated cleaners are capable of microetching most alloys of aluminum if run too hot and/or at excessively high concentrations.

**Organic acid cleaners.** Organic acid cleaners use a high concentration of organic surface active agents, called surfactants, to remove stains, streaks and related blemishes. They are expensive, but long bath life may justify their use.

**Acid etching cleaners.** Acid etching cleaners, containing phosphoric acid, hydrofluoric acid, wetting agent and solvents such as ethylene glycol or propylene glycol, are employed to remove light soil and are useful in preparing aluminum for chromating or direct painting. The acid provides a smooth microetched surface that is highly suitable for the formation of a chromate conversion coating.

**Alkaline etching cleaners.** Alkaline etching cleaners are used in hot, strong sodium hydroxide (caustic soda) solutions containing chelates and wetting agents. These cleaners produce a heavily etched surface that is visible after the black oxides (smut) produced by strong alkali are removed by an acid dip.

To ensure an acceptable operating environment, a blanket layer of detergent foam on parts to be cleaned is needed to suppress the alkaline fumes that result...
from the reaction between aluminum and the hydroxide. If the foam blanket becomes depleted due to oils from the parts, a small amount of high-foaming detergent can be added. Parts should be reasonably clean prior to etching in order to avoid the formation of blotches on the aluminum.

Figure 1-5. pH Scale Measures Alkalinity and Acidity

pH is a measure of the acidity or basisity of solutions. The approximate pH values of some common materials are given. Note that lower pH numbers indicate greater acidity.
Rinsing After Cleaning

In addition to the discussions so far, there are other aspects of the cleaning process that are also important. Good rinsing after cleaning is crucial; for example, poorly rinsed caustic cleaners can interfere with subsequent phosphating by coarsening phosphate crystals and promoting void areas where no phosphate coating is formed. The phosphate chemicals are thus wasted because they react with the caustic materials to create insoluble sludge. Additional cost is incurred because the sludge must be treated. Surfactant solutions need to be rinsed thoroughly from surfaces to be painted. They are often not easy to rinse, however, and can reduce the quality of the phosphate coating.

The water quantity, quality and temperature all play a part in determining the efficiency of the rinse. A simple check of the quality of rinse water can be made by measuring the conductivity of the final drain-off rinse. Rinse water can be collected from the parts, or a small portion of the drain-off can be evaporated; high conductivity in the rinse or visible spot residues on the parts indicate marginal rinsing. Total dissolved solids should be minimal. In some paint systems the dissolved solids in the rinse water are held as low as 10 parts per million (ppm) or below 30 micromhos conductivity. For less sensitive systems the dissolved solids can be as high as 100 ppm. In order to reduce high conductivity, a brief deionized water rinse may be required after the normal supply water rinse.
Chapter 2

Conversion Coatings

The importance of a clean surface prior to painting cannot be overemphasized; however, a clean surface may not be all that is needed. Whether or not additional surface chemical treatment is required depends on the substrate to be painted.

In the case of wood, a clean surface is all that is required (excluding surface smoothness considerations). A wood surface is unique because its polar cellulosic composition provides an excellent adhesion base for paints.

Although a clean wood surface never requires chemical treatment before painting, this is not true with plastic surfaces. Some plastics can be painted directly after cleaning and achieve good paint adhesion; others—primarily the low-polarity plastics, such as polyethylene and polypropylene—require additional treatment to enhance surface adhesion.

To improve paint adhesion, plastic surfaces can be oxidized by electrostatic discharge, controlled flame or by using oxidizing paints. Such oxidative treatment introduces carboxyl (COOH), carbonyl (CO) and hydroxyl (OH) groups into polymer molecules on the plastic surface. The presence of these groups can be verified by reflective infrared spectrophotometry.

As with plastics, some metals are painted immediately after surface cleaning. These metals, however, usually do not have severe requirements for adhesion or corrosion resistance. Low-price products that are expected to have a short life cycle may fall into this category.

Conversion Coatings for Metal

Most metal products that are to be painted receive a “conversion coating” after cleaning. A conversion coating is a chemically developed surface coating that helps shield the metal from air, moisture, industrial gases and the like, thus increasing corrosion resistance and simultaneously providing a roughened surface to improve paint adhesion. The conversion coating surface has microporosity and
microroughness in the form of pores, fissures and undercuts that form an excellent stratum into which the paint can flow and create “fingers” for a good hold onto the surface. In addition, the conversion process leaves a slightly acidic residual pH on the surface, which is more receptive to good paint adhesion than is an alkaline pH. Alkaline solutions can degrade paint resins and find use in paint strippers; alkalinity on surfaces to be painted is generally undesirable.

Long-term paint adhesion is enhanced by the thermal expansion and contraction buffer provided by the conversion coating between the metal and the paint. The expansion and contraction coefficient of the paint film is many times that of the underlying metal. The conversion coating is intermediate in its expansion and contraction characteristics. As a result the severity of the difference in the expansion rate between the paint film and the underlying metal is lessened when sudden hot and cold changes are experienced.

A conversion coating reduces the lateral creep of corrosion away from gouges and scratches that have gone through the paint down to bare metal. The conversion coating inhibits the undercutting of the paint by loss of the underlying metal, and the spread of rust away from a scratch line is slowed significantly.

Conversion coating thicknesses are given in weight per unit area. In the United States the reading is traditionally in mg/sq ft. Conversion coatings for metal surfaces to be painted may vary from a few mg/sq ft to as much as 500 mg/sq ft. Conversion coating thicknesses are usually specified within a certain range for optimum adhesion and corrosion resistance for a given product.

Conversion coatings are usually formulated specifically for a particular type of metal and may differ in chemical composition and anticorrosion properties. Metals used most commonly in manufacturing and of primary interest in industrial painting are hot- and cold-rolled steels, stainless steel, clad and metal-coated steel, hot-dip galvanized steel, electrogalvanized steel, die-cast zinc and aluminum alloys.

Conversion Coatings for Steel

Conversion coatings for steel are usually either iron phosphate or zinc phosphate. Somewhat different chemicals are used in iron phosphating than in zinc phosphating, but the overall processes are similar. They both include a dilute aqueous solution of phosphoric acid containing a soluble type 1 phosphate salt.

An important prerequisite for applying a phosphate coating is to have a thoroughly clean surface. All traces of the cleaning solution must be removed. Unrinsed alkaline cleaner, for example, can reduce the quality of the deposited phosphate coating.

In the phosphating process the acid attacks the metal surface, removing soluble iron into the coating bath and lowering the acid strength at the interface of the metal and the phosphating solution. In the area of the metal surface where the acid...
strength has been depleted, the type 1 (primary phosphate salt) converts to type 2 (a monohydrogen phosphate salt) and then immediately to a type 3 (tertiary) phosphate.

In iron phosphating, type 3 iron phosphate is formed; in zinc phosphating type 3 zinc phosphate is formed. Both type 3 phosphate salts are insoluble and form out of the phosphate solution, tightly bonding to the metal surface.

Additional chemicals such as accelerators and oxidizers are present in the phosphating solution. Accelerators are added to keep the many chemical reactions occurring at the correct rate.

When ferrous metals are phosphated, the oxidizers convert the iron dissolved by the acid from the +2 to the +3 oxidation state and at the same time they also prevent the formation of large hydrogen bubbles on the surface of the metal. Hydrogen forms by the reaction of acid and steel. To prevent hydrogen bubbles from blocking access of the acid solution to the metal, oxidizing agents convert the hydrogen to water.

Most iron phosphates and zinc phosphates have a clear to a dull gray appearance; however, the addition of molybdic acid or a molybdate salt added as a corrosion inhibitor will give an extremely purple cast to some iron phosphate coatings.

Process time, temperature and chemical concentrations are the three basic factors that affect the chemical reaction in a phosphate process. The process time is dictated by the speed at which the conveyor line must run. Temperature and concentration of the solutions are the conditions that are monitored during phosphating.

The bath temperature can dramatically affect phosphating deposition. If the temperature of the preceding stage—such as a cleaning stage—is lower than that of the phosphate stage, problems can develop that will eventually diminish phosphate quality and increase solution maintenance. With low cleaner and rinse stage temperatures, the heating burden shifts to the phosphate stage. The increased demand for heat in the phosphate stage forms excessive sludge. The extra sludge will plug risers and spray nozzles and reduce heating capacity by building scale on the heat exchanger. The reduced heating capacity will drop the temperature of the phosphating bath below specifications. For the phosphate to coat properly under these conditions, a high level of accelerator is required, which will generate even more sludge.

**Iron Phosphating**

Iron phosphate coatings, sometimes called amorphous or noncrystalline iron phosphate, are a mixture of iron oxides and iron phosphate. The typical coating weight of iron phosphate is 25 to 100 mg/sq ft. Iron phosphate characteristics include: moderate corrosion resistance, relatively low operating costs, simple equipment requirements, low sludge formation and moderate control requirements.
The main variables to regulate and monitor are the treatment times, solution temperatures and solution concentrations. Iron phosphating can be done with ambient (room) temperature solutions; most, however, operate at between 120°F and 140°F.

Iron phosphating and cleaning are usually not done in the same bath, but it is possible to clean and iron phosphate simultaneously in a single solution containing a suitable cleaner and phosphating chemicals. Such a combined solution, however, almost always provides inferior cleaning and phosphating than when these procedures are done separately. The combination solution is usually satisfactory only if the parts have extremely light soils.

All too often plants install combination cleaner/phosphate systems and later find them inadequate. Soils may be light on the products for which the cleaner/phosphate is first designed, but subsequent changes in the type or source of metal used or different manufacturing processes may introduce heavy oils or other contaminants that cannot be fully cleaned in a combination bath. Then expensive retrofitting must be done to add a separate cleaning stage and another rinse stage. This can only be done if enough floor space is available. Separate cleaning and phosphating stages are almost always desirable.

One application where combination cleaner/phosphate baths are practical is with manual spray wand pretreatment of products that are too large for a conveyor. In such applications a steam generator provides the necessary heat to the combination cleaner and iron phosphate solution.

**Zinc Phosphating**

Zinc phosphate comes in a number of formulations. Pure zinc phosphate is called hopeite. Zinc phosphate coating weights are typically 175 to 450 mg/sq ft on steel that is to be painted. Little increase in adhesion or corrosion resistance is gained from depositing heavier coating weights.

The formation of a fine, dense crystal pattern of zinc phosphate (Figure 2-1) noticeably improves corrosion resistance and paint adhesion compared with coarse zinc phosphate crystals (Figure 2-2). One of the most common ways to produce a fine, dense crystal pattern is to add titanium phosphate either to the zinc phosphating solution or to the rinse preceding the zinc phosphating stage. These titanated rinses neutralize trapped cleaning agents, orient crystal growth in a configuration parallel to the surface and initiate the growth of fine, dense crystals. Titanium ions act as nucleation sites for phosphate crystal growth wherever minute amounts of titanium are adsorbed on the steel surface.

Incorporating iron ions into zinc phosphate coatings as they are forming will produce iron-rich zinc phosphate. The alkaline-resistant material is known as phosphophyllite, $\text{Zn}_2\text{Fe}(\text{PO}_4)_2$. Phosphophyllite's strong tensile properties reduce crystal fracture under stress. Its increased alkali resistance diminishes the rate of creepback from areas where corrosion has already begun from a paint scratch or
Conversion Coatings

Many modern finishing systems regularly process parts with zinc surfaces. As is true for steel, the best conversion coating for zinc is a zinc phosphate. Because electrogalvanized and pure zinc react rapidly with zinc phosphate solution, other metal ions should be added to slow the rate of coating deposit and limit coating weight. Nickel and ferric iron are widely used for this. Some hot-dip galvanized surfaces containing aluminum are difficult to phosphate. Fluoride activation can be used to initiate reaction and tie up dissolved aluminum that would otherwise poison the bath.

A typical zinc phosphate coating formulated for zinc can also be used for steel; such a formulation generally uses nitrite—typically added as sodium nitrite—to accelerate phosphate coating formation and to control the solution's iron content. As an oxidizing agent, nitrite readily oxidizes ferrous iron. With hot-dipped galvanized steels, a nickel- or cobalt-activated bath can cause white pinpoint deposits or "seeds" that can sometimes be seen through the paint. These appearance defects are eliminated if fluoride ion is also present in the bath. Oxalic

from damage by a stone chip.

Although zinc phosphating baths can be operated at temperatures as low as 85°F and as high as 180°F, most are maintained at about 140°F. The concentration of phosphating solutions must be maintained within a narrow range when the operating temperatures are lowered, necessitating frequent titrations to maintain proper chemical levels.

Combination cleaning/zinc phosphating stages are not available because of the impossibility of doing both in the same solution. A separate cleaning stage is required with zinc phosphate.

Conversion Coatings for Zinc
acid (COOH)$_2$ systems can be used, although in practice they are extremely rare. When parts with different types of metal are run on a phosphate line, it is preferable to mix the parts randomly on the conveyor.

The majority of iron phosphating formulations do not produce any noticeable amounts of coating on zinc, whether electrogalvanized, hot-dipped galvanized or die-cast. Iron phosphating will remove thin layers of oxide from the surface and, if maximum corrosion resistance is not essential, it may be satisfactorily used as a prepaint treatment on zinc substrates.

**Specialty Phosphates**

For years the appliance industry has used a microcrystalline calcium-modified zinc phosphate bath that gives good corrosion resistance, but which needs a relatively high process temperature close to 160°F for consistent coating. This material is an extremely heavy sludge producer. If the phosphate stage of a washer is to use this high-temperature solution, the equipment may have to be modified because of thermally inverse solubility problems with some of the chemicals. Heaters for the solution should have a large surface area and only a moderate temperature gradient, rather than running full bore at high temperatures with a small heat tube surface area. This will prevent localized hot spots from forcing substances with inverse solubilities out of the solution.

A lower temperature system works fairly well but requires extra cleanliness for good operation. Temperature control often has to be within ±2°F for good operation and the concentration of the grain-refiner chemicals is extremely crucial with this process. Although stainless steel is rarely phosphated, when it is it is treated somewhat like zinc and the phosphate system should contain fluoride.

Many related processes fall under the headings of iron phosphating and zinc phosphating and dozens of manufacturers formulate and sell the chemicals and the many proprietary ingredients used.

**Spray and Dip Processes**

Phosphating solutions can be applied to metals either by spray, immersion or by combinations of the two. Spray application (Figures 2-3 and 2-4) promotes fast crystal growth because fresh solution constantly impinges on the surface at pressures of roughly 15 to 25 psi. However, recessed areas do not receive much coating because of the difficulty in spraying solution into these areas.

The immersion (dip) process has a number of distinct advantages, although it is slow and requires a large body of solution, especially in conveyorized lines. The advantages include:

- Higher coating weights can be achieved
- An immersed zinc phosphate coating can be rich in iron
Figure 2-3. Automatic Spray Line (left) and Dryoff Oven (right)

Figure 2-4. Applying Phosphate with Manual Spray Wand
A high quality and fine crystal structure is produced.
- It is relatively easy to maintain because no nozzles have to be cleaned. The problem of clogged nozzles that interfere with the overall phosphate quality is avoided.
- No heat is lost from spraying hot solutions.
- Sludge formation is minimal.

New automotive painting facilities installed in recent years use immersion cleaning and phosphating to increase corrosion resistance. For years Chrysler used a combination spray plus dip process known as the “slipper dip” method. The lower half of the bodies were immersed to increase rust protection.

A typical system for phosphating either iron or zinc parts would have five stages:

1. alkaline clean
2. rinse (single or double)
3. phosphate
4. rinse
5. sealer rinse

Zinc phosphating sludge includes salts of zinc and iron (principally iron oxides and phosphates), spent accelerator and oxidizer. Phosphate sludges may be allowed to settle and then be removed, or they can be continuously filtered out. Excessive sludge is produced when very hard water is used; deionized or softened water may be economical for this reason.

**Phosphate Troubleshooting**

Troubleshooting problems in phosphating prior to painting requires a considerable knowledge of cleaning, rinsing and phosphating. The troubleshooting process generally should employ three steps:

- Determine the problem.
- List the probable causes of the problem
- Review the possible remedies to correct the problem

The following is an examination of five categories of phosphating problems. Each problem is first stated and discussed. Then, possible causes are listed, and the possible remedies are reviewed.

**PROBLEM 1**

**Streaky, Blotchy, Thin or Discontinuous Phosphate Coatings**

Streaky phosphate coatings might not reduce corrosion resistance, but blotchy, thin or discontinuous coatings will. It is good practice to take corrective action to obtain phosphate with a uniform, light- to medium-gray, tight-grain crystal structure.
Possible Causes
- Excessively dirty metal entering the cleaning stage.
- Failure to remove contaminants such as sealants, dried drawing compound or heavy oil deposits.
- Inadequate solvent preclean.
- Dirty solvent, rags or sponges.

Possible Remedies
☐ Ensure that equipment is properly maintained and that chemical concentrations, cleanliness and temperature requirements are met.
☐ Check if sealant is applied only where specified. Remove excess sealant prior to parts cleaning stages. (Excess sealant will contaminate chemicals, plug nozzles and alter the correct solution spray pattern on parts.)
☐ Review the prewash process.

Possible Causes
- Weak cleaner concentration.
- Low temperature and pressure in cleaner stage.
- Inadequate rinse after the cleaner stage.
- Drying of parts between stages due to the cleaner bath being operated too hot.

Possible Remedies
☐ Review phosphate process procedures and make necessary changes to temperature, spray pressure and chemical levels.

Possible Causes
- Contaminated cleaner.
- Plugged or misaligned nozzles.

Possible Remedies
☐ Make daily checks of nozzles to correct misalignment and replace plugged nozzles. High spray pressures can indicate that some nozzles are plugged.
☐ Remove accumulated dirt from the cleaner.
☐ Ensure that the filtering system works properly.
☐ Drain, clean and recharge the tank at necessary intervals to keep it operating effectively.

Possible Causes
- Low accelerator or high free-acid concentrations.
- Other chemical imbalances.
- Poor bath agitation.

Possible Remedy
☐ Make chemical additions as needed. (Low accelerator or high free-acid concentrations lower the ratio of total acid to free acid.)
Possible Cause
- Stained, discolored or oxidized metal surface.

Possible Remedy
☑ Remove defect by wiping with acid and/or abrasive before parts enter the cleaning stage. Do not allow acid to dry on parts. Rinse thoroughly with water when acid is used.

Possible Cause
- Drips of chemicals from washer roof or conveyor.

Possible Remedies
☑ Adjust nozzles to avoid spraying the roof or the conveyor.
☑ Install or adjust drip pans to catch drips.
☑ Reconstruct the enclosure to have a domed roof and/or move the conveyor outside the washer enclosure.

PROBLEM 2

Loose, Powdery and Nonadherent Phosphate Coatings

Loose, powdery and nonadherent phosphate will not provide adequate adhesion to metal and will reduce corrosion resistance. The crystalline structure will not be tight or dense, and crystals will be larger than normal. This phosphate coating can be easily wiped off.

Possible Cause
- High total acid/free acid (TA/FA) ratio in the phosphate stage.

Possible Remedy
☑ Correct the TA/FA ratio by adding phosphate makeup material per instructions.

Possible Cause
- High accelerator concentration.

Possible Remedy
☑ Add fresh water to reduce the accelerator content. Recheck the total and free acid concentrations and add phosphate makeup as required. (Excess accelerator will neutralize the free acid content and will cause a high TA/FA ratio. A high TA/FA ratio will yield powdery, nonadherent coatings.)

Possible Cause
- Poor cleaning.

Possible Remedy
☑ Check to ensure that the cleaner concentration, pressure and spray
impingement are adequate. If the cleaners are excessively dirty, dump the cleaner stage, clean the tank and recharge. Inspect all solvent-wipe operations to ensure properly cleaned exterior surfaces. (If cleaning is inadequate, the quality of the phosphate coating will be poor.)

Possible Cause
- Slow line speeds or frequent line stops.

Possible Remedy
☑ If line speeds are operating below design capacity, and if line stoppages are frequent, it may be necessary to reduce the phosphate chemical concentrations. Check with the phosphate supplier for recommended concentration reductions.

PROBLEM 3
Salt Deposits, Acid Spots and Water Spots

If phosphate salt deposits, acid or water spots remain on the metal surface they will act as contaminants. They may have adequate adhesion to the metal but will usually be the starting point for humidity blistering or scab corrosion. Since they degrade the overall corrosion protection, they must be corrected immediately.

Possible Cause
- The overhead conveyor drips onto parts due to chemical buildup and condensation.

Possible Remedies
☑ Adjust nozzles and/or pump pressure to avoid spraying the conveyor.
☑ Adjust overhead drip pans to catch dripping.

Possible Cause
- Inadequate water rinsing after phosphate stage or after sealer rinse stage.

Possible Remedies
☑ Check nozzles in the water rinse stages for inoperative or plugged conditions.
☑ Determine if stages provide sufficient rinse water for thorough removal of residual chemicals. Large-capacity rinse tanks and/or pumps, additional risers and/or extension of rinse risers may be required.

Possible Cause
- Parts drying due to line stops.

Possible Remedies
☑ Ensure that water rinses are activated during all line stops.)
Possible Cause
- Deionized rinse water may be too high in solids content and/or conductivity.

Possible Remedy
☑ Check the deionized water. If necessary, recharge the deionizer. When recharging, flush all chemicals from water lines prior to rinsing.

PROBLEM 4
Flash Rust

If the metal is oxidized or rusted, corrosion resistance may or may not be affected. The rust or oxidation severity will vary, depending on the cause. Corrective action is required.

Possible Cause
- Low accelerator concentration.

Possible Remedy
☑ Adjust the accelerator concentration. A low accelerator concentration will imbalance the TA/FA ratio, resulting in a thin coating susceptible to flash rusting.

Possible Cause
- Incorrect total TA/FA ratio.

Possible Remedy
☑ Correct the ratio. A low total acid value or excessive free acid value will result in thin coatings that may flash rust.

Possible Cause
- Drying between stages.

Possible Remedy
☑ Avoid overheating any stages. Install misting nozzles between stages to keep parts wet. Due to high temperatures, line stoppages or insufficient rinsing, the drying of parts between stages may occur. This usually results in flash rust.

Possible Cause
- A weak or insufficient spray pattern in the phosphate stage.

Possible Remedy
☑ Check for plugged or misaligned nozzles and for low pressures—these may alter the phosphate spray pattern, resulting in discontinuous or thin coatings. These conditions will usually produce rust. Correct as required.
Possible Cause
- Rust on metal prior to phosphating.

Possible Remedy
- Remove all rust prior to phosphate by mechanical abrasion or acid strippers. When acid is used, thoroughly rinse with water. Acid must not be allowed to dry on the parts. Rusted parts entering the phosphate systems will result in rusted parts exiting the phosphate system.

Possible Cause
- Stripping of phosphate coating in the chromic acid rinse stage.

Possible Remedy
- Minimize line stoppages. Check the chromic acid concentration. (If a phosphated part stops in a chromic acid sealer rinse, or the acidity of the chromic acid is too strong, stripping of phosphate coating may occur and allow flash rusting.

Sealing Phosphate Coatings

Even when phosphating is done perfectly, one or two percent to as much as five percent of a surface will not be phosphate-coated because of hydrogen gas bubbles forming pin holes and crevasses that prevent crystalline growth due to interference with the phosphoric acid attack on the metal.

Improved corrosion resistance can be attained when these open areas are sealed with an inhibiting material. A chromic acid rinse or a chrome-free sealer rinse can be used. Even more effective is an acidic mixture of trivalent (Cr³⁺) and hexavalent (Cr⁶⁺) chromium compounds known as “reduced chromic acid.”

Typically the chromic acid rinse is used to accomplish these purposes:
- Remove possible traces of unrinsed phosphate solution. Phosphate chemicals are hygroscopic and are able to pull water out of the air—if they are not thoroughly removed the result may be early blistering of the paint film.
- Remove loosely attached conversion coating deposits.
- Greatly enhance corrosion resistance by sealing open areas or pores in the phosphate coating and by leaving behind residual amounts of the chromate ion antitrust agent.

If an extremely dilute chromate solution is used the part can proceed to a dryoff oven and then be painted. Better results are frequently obtained when a more concentrated sealer rinse is used. But this requires that the sealer be rinsed afterwards. Unfortunately, the materials deposited by the sealer are less soluble than the phosphate coatings. If a thorough rinse were to be used, all the newly applied sealer material would be rinsed away. For this reason a brief compromise rinse is used of about 20 to 30 seconds duration. This removes the excess solution without removing the deposited sealer compounds.
Because of the extreme toxicity of chromium, various nonchrome sealer materials have become available. Depending largely on the paint materials that are applied, nonchrome sealers may rival chromium-containing materials in anticorrosion performance.

Nonchrome, nontoxic materials that can run directly to drain after possible pH adjustment and dilution are increasingly being used in industry. Most of these are acidic, but a few are alkaline. They are in many cases as effective as chromic acid rinses, but their performance cannot be expected to exceed that of chromium. A deionized water spray rinse is usually employed after the sealer.

**Conversion Coatings for Aluminum**

An aluminum surface should be conversion coated prior to painting. Aluminum very quickly forms a natural oxide layer that provides only poor to fair adhesion for paint. Like other metal surfaces, aluminum needs to be cleaned before receiving a conversion coating. Aluminum must be cleaned properly to avoid smut (black oxide), which can form when strongly alkaline cleaning solutions are used, although the smut can be readily removed with nitric acid.

The choice of the proper conversion coating for a particular aluminum product depends on whether the product is being processed alone or with other metals. When only aluminum is involved, a chromate is superior and is usually the method of choice. If aluminum is processed along with zinc and/or steel, then a phosphating treatment would be more appropriate, depending on the relative amounts of each metal to be run.

Chromate is the real workhorse of aluminum conversion coatings. It is also known generically as chrome oxide and amorphous chromate. Chromate provides outstanding paint adhesion and corrosion resistance, especially when sealed with a chromic acid rinse. Chromate processes are most frequently used on aluminum but can also be used on cadmium, copper, magnesium, zinc and titanium to provide corrosion resistance and paint adhesion. Chromate can be used on iron but is less effective than the phosphates.

Chromate coating weights normally range from 10 to 80 mg/sq ft, but most plants apply weights of 25 to 35 mg/sq ft. Higher coating weights, of course, increase corrosion protection. Heavy coating weights are common for aluminum parts used in water, such as the outboard components of boat motors and drives.

Below 10 mg/sq ft, chromate is colorless. This low coating weight is sometimes used when clearcoats are applied to aluminum, such as on styled aluminum auto wheels. This invisible chromate coating provides some extra adhesion and corrosion resistance without discoloring the aluminum. At 10 mg/sq ft the coating contains very little hexavalent chromium.

At about 15 mg/sq ft, chromate coatings begin to exhibit an iridescent light
yellow-golden color. As additional coating weight develops, however, it forms an increasingly golden appearance and then a darker metallic tan or brownish-bronze color. The exact shade is determined by the pH, concentration of the bath, duration in the bath, spray pressures and surface roughness.

The various chromating processes include those with accelerated and nonaccelerated coating baths. One of the oldest and best (but highly toxic) accelerators is the ferricyanide ion. A coating using an iron ferricyanide accelerator has the composition, \( \text{CrFe(CN)}_6 \cdot 6 \text{Cr(OH)}_3 \cdot \text{H}_2\text{CrO}_4 \cdot 4\text{Al}_2\text{O}_3 \cdot 8\text{H}_2\text{O} \). Safe accelerators, such as molybdate and molybdate/zinc, are now more commonly used.

In general, chromate conversion coatings produced by nonaccelerated baths are quite durable, but the processes are slow and require frequent bath replenishment. Nonaccelerated baths also have short working lives. The nonaccelerated coating typically has the representative composition of, \( \text{Cr(OH)}_2 \cdot \text{H}_2\text{CrO}_4 \cdot \text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O} \).

Chromating solutions contain chromic acid and hydrofluoric acid at a pH of 1.5 to 2.0 and a lot of hexavalent chromium. While amorphous chromates can be applied by immersion or by spraying. Immersion is far more frequently selected because of the inherent dangers in spraying toxic chromium solutions. The newly chromated coating is subject to two types of damage. The fresh coating is soft and easily abraded, and the unpainted chromate is heat-sensitive. A maximum skin temperature for chromated parts during dryoff (usually with hot air) prior to painting is 140°F. Even 10 minutes at 300°F will cause noticeable chromate decomposition. Once the parts are painted, however, heat no longer causes significant deterioration, and paint oven temperatures can be as high as required without degrading the chromate. The difference is presumed to be due to the exclusion of oxygen plus the effective sealing of the water of hydration in the crystals by the paint layer. Heat destroys chromate effectiveness by altering the chemical composition of the film by expelling the water of hydration in the crystal structure. A color change to a bluish-purple with a powdery look is seen when overheating occurs. Loss of the water of hydration shrinks the crystals and results in bare metal areas devoid of conversion coating.

**Phosphate for Aluminum**

Iron, zinc and chromium phosphate coatings can be used on aluminum with various levels of effectiveness. Iron phosphating solutions usually deposit little or no coating on aluminum, but they rather effectively clean the surface. Many aluminum alloys exhibit good paint adhesion with only this weak acid cleaning. Some iron phosphate systems leave a small amount of coating on the aluminum, but this is probably a mixture of iron and aluminum oxides rather than a true
phosphate. The coating composition will vary widely with the dissolved iron concentration in the bath. When production involves mixed metals with steel plus a small amount of aluminum, the preferred pretreatment is likely to be an iron phosphate.

Zinc phosphating generally would be used on aluminum only if steel and/or zinc were also being surface-converted. A fluoroborate or fluoride additive in the bath is necessary to etch the aluminum. The hydrogen fluoride that is formed will remove the aluminum oxide on the surface and allow acid attack on the metal. The fluoride ion also acts to precipitate aluminum as aluminum fluoride (AlF₃) to avoid poisoning of the bath by aluminum ions.

Zinc phosphate produces a clear-to-light-gray coating on aluminum, much the same in appearance as the zinc phosphate coatings on steel and zinc. The immersion-produced zinc phosphate on aluminum, as is true on steel and zinc, gives better corrosion resistance than spray-applied zinc phosphate.

For small amounts of aluminum to be processed, a chromium phosphate pretreatment may be used. The aluminum is first cleaned, usually by spray. The chromium phosphate bath contains a mixture of hydrofluoric, phosphoric and chromic acids. The weights of coatings produced range from about 25 to 200 mg/sq ft; the normal amount is approximately 40 to 60 mg/sq ft. At around 20 mg/sq ft, chromium phosphate is pale green. The color darkens as the coating weight increases. It is middle to dark green between 150 to 200 mg/sq ft.

A typical chromium phosphate coating is Al₂O₃ • 2CrPO₄ • 8H₂O. It contains no hexavalent chromium (Cr⁶⁺) and has the approval of the U.S. Food and Drug Administration for use as a conversion coating inside food cans. Chromium phosphate coatings are somewhat more heat tolerant than chromate coatings.

At least one chemical supplier has dried-in-place, no-rinse chromium phosphate. The coating produced is based on tannic acid, tannates, zirconates or related anions, but little detail is available on its chemistry. Another company has a similar dried-in-place, no-rinse material for aluminum based on either titanium or zirconium chemistry. The principal advantage of no-rinse systems is the absence of toxic waste; nothing goes down the drain. The no-rinse coatings are low in coating weight and chemically low in resistance to corrosive attack. Thus their usage is limited to parts where corrosion resistance is not a major consideration.

A chromic acid sealer will increase corrosion resistance, but the coated metal cannot be used for food container applications because the chromic acid contains hexavalent chromium. A number of Cr⁶⁺ compounds are known carcinogens.

Where heating of conversion-coated aluminum parts cannot be avoided because of a particular manufacturing process, one of the chrome phosphate conversion coatings would be a wise choice. All conversion coatings, even iron and zinc phosphates, are harmed by excessive heat, but the amorphous chromate is the most heat-sensitive of them all. The phosphates are the least susceptible to thermal damage.
Anodizing of Aluminum

Another type of conversion coating for aluminum is anodizing, which is the electrochemical deposition of an oxide coating on the aluminum surface. It is not an exceptionally effective prepaint coating.

Two of the major virtues of some anodized coatings are their corrosion resistance and hardness. These factors are important in the aircraft industry; planes encounter considerable abrasion from sand, airborne particles, raindrops, cold-weather icing, sleet, hail and snow. For protection of the thin aluminum skin, the anodizing is far more important than a layer of paint.

Anodizing is usually done in a dilute acid, such as chromic, oxalic or sulfuric. The aluminum part is made the anode of an electrolytic cell while immersed in the acid medium. The resulting oxide forms a tight uniform layer about \( \frac{1}{4} \) mil thick that weighs 500 to 2000 mg/sq ft. The process is very slow and to form 1000 mg of oxide may require 15 or even 20 minutes. Initially the oxide film is soft and somewhat gelatinous, but on drying it becomes very durable.

Pores in the newly formed oxide coating can be sealed effectively by immersion in hot water or in aqueous solutions of corrosion-inhibiting substances. A unique process simultaneously hydrates and impregnates the anodized coating with a polyurethane resin.

In contrast to the 1000 mg/sq ft coating weights for aircraft, heavy anodized coatings of up to 5000 mg/sq ft are mandated by military specifications for aluminum used in underwater applications. Anodizing done in cold solutions produces a much harder oxide layer than in warm solutions. Anodizing bath temperatures as low as 20°F have been used.

Chromic acid anodizing is considered the best type of anodizing for paint adhesion. It has been preferred in the aircraft and aerospace industries because it causes the least fatigue stress to be induced in the aluminum of spacecraft. The recent trend is to use sulfuric acid processes, however.

Other Conversion Coatings

In addition to those discussed above, other conversion coatings are available, but are generally intended for corrosion resistance and not as a base for paint. Of these, various blueing, browning and blackening oxide coatings provide minimal corrosion resistance for iron and steel.

Heavy manganese phosphate coatings (as much as 2500 mg/sq ft) are applied on friction surfaces of gears and bearings to stop scoring during break-in periods. In rare instances lead phosphate is used as a conversion coating.
Conversion Coating Waste Treatment

Conversion coating solutions and rinses need to be treated before discharge to drain if they do not conform to local, state and federal discharge codes. Discharge regulations almost always prohibit hexavalent chromium and certain heavy metals beyond specified concentrations. Limits on phosphate concentrations in waste water are also established for many locations.

The cost of the chemicals is too low to consider trying to recycle them. It is likely that the efficiency of the solutions would be reduced anyway if an attempt were made to recycle. It is cheaper simply to buy new chemicals.
Chapter 3

Paint Components and Their Functions

The term “paint” had a simple definition before about 1960. It was defined as a liquid containing a binder (also called resin, vehicle or polymer), solvent, additives and possibly pigment, as shown in Figure 3-1. The binder was thought of as the film-former. The solvent was considered a means of giving the binder the desired viscosity for application. Additives provided certain unique characteristics for a particular paint. The pigment (if present) supplied color and film strengthening.

After about 1960 various new “paints” were developed that didn’t fit the old definition of paint. Powder coating came onto the scene. Lacking a solvent, could it be called a paint? Electrodeposition (electrocoating) was invented. Could a bath of a chemical liquid that required electricity for its deposition be a paint? Various 100 percent solids (containing no volatiles) liquid “paints” were introduced.

Figure 3-1. Paint Composition by Volume
Lacking solvent, could they be called paints? As the old definition of paint began to be strained because of the new developments, the term “coating” began to grow in popularity. What didn’t fit the paint definition was conveniently called a coating. A paint became “not necessarily a coating,” and a coating included all paints and anything else that resembled paint but didn’t fit the old paint definition.

To confuse the issue further, once a paint or coating is applied and cured, the two terms lose their slightly different meaning. Any applied and cured paint or coating can be called either a paint or a coating. An applied and cured powder coating film, electrocoating film or 100% solids coating film can be called a paint film.

To simplify things, this chapter will discuss only “paint.” Powder coating, electrocoating and 100% solids coatings will be discussed elsewhere in this book.

Paint is prepared by mixing a particular binder or binder combination, solvent or solvent blend, additives and, perhaps, pigment or group of pigments together in an exact way to produce a specific formulation that, when cured, will possess certain properties. The cured film contains all of the ingredients present in the liquid paint except the solvent, which evaporates during the paint application and curing processes. A paint film very closely resembles a layer of plastic. In fact, a totally organic paint film is identical in almost every way to plastic.

### Binders

A binder is the liquid resinous part of a paint that holds all of the paint’s constituents into a continuous system and which, after application onto a surface, enables the paint to cure into a paint film. The binder is the most important component of a paint.

The resinous material in binders is made up of polymers. A polymer in organic chemistry is a chain linkage of many repeating individual chemical structures. The polymers used in binders tend to be highly viscous and therefore are generally thinned with solvent. The solvent-thinned polymers are termed vehicles. A paint manufacturer will usually buy a binder polymer material in the vehicle form.

Polymers for paints can be categorized into various types, depending upon how they form a cured paint film. These are lacquers, auto-oxidation film formers, nonauto-oxidation film formers, free radical polymerization-curable film formers and emulsion-type film formers.

- A lacquer consists of a polymer dissolved in a solvent. Lacquers form paint films by simple evaporation of the solvent, which permits the polymer particles to coalesce into a continuous film.
- Auto-oxidation film formers consist of molecules with carbon-carbon double bonds that oxidize in the presence of atmospheric oxygen to form a cross-linked paint film. These polymers are primarily alkyds, natural oils and epoxy esters.
Nonauto-oxidation film formers contain two polymers: a backbone polymer such as an alkyd, and a cross-linking resin, such as melamine or urea-formaldehyde. In the presence of heat and a suitable catalyst, the backbone polymer and cross-linking agent cross-link into a paint film.

When free radical-curable film formers are exposed to electron beams or ultraviolet light, they cross-link into a paint film, often within seconds. While some contain volatile solvents, others are either 100% solids or 100% nonvolatile. In some cases small molecule polymers with low viscosities are used to avoid the need for solvents. With higher viscosity polymers, various "reactive diluents" that cross-link and become part of the cured paint film can be used.

Emulsion-type film formers are similar to lacquers in that evaporation of the “solvent” (usually water plus one or more actual solvents) results in coalescence of the polymer particles. Acrylics and vinyls are among polymers used to make paints of this type.

The types of polymers used in binders include acrylics, alkyls, aminoplasts, celluloses, epoxies, chloro- and floro-carbons, natural plant oils, phenolics, polyesters, polyurethanes, silicones and vinyls. The chemistry of these polymers and various cross-linking resins is exceedingly complex. Some idea of the complexity is to state that a backbone polymer needs hydroxy (−OH), carboxy (−COOH) or amide (−CONHz) functionalities in order to cross-link with amino cross-linking resins. The organic chemistry of these polymers and their cross-linking systems is beyond the scope of this book but is discussed in detail in any organic chemistry text.

A binder must be completely transparent to prevent interference with the shade and color of the pigment. The binder must not be susceptible to yellowing or discoloration with age or from exposure to long periods of sunlight, because this would gradually shift the color of the film. Certain impurities in binders can contribute to such discoloration.

In addition to serving as a paint's “heart,” a binder needs to perform a number of important functions. These include:

- Bonding
- Encapsulating the pigment
- Flowing out
- Providing the required physical properties

**Bonding.** The binder needs to grab hold of the substrate in a bonding action. This is achieved largely by mechanical keying into the slight roughness of the surface of the substrates. It is difficult for paint to adhere to extremely smooth surfaces such as glass and plated chrome.

**Encapsulating the pigment.** Each pigment particle must be completely wetted out and surrounded by the binder. The binder should encapsulate and hold the pigment particles separate, not allowing them to cluster (aggregate). Clustering reduces the effectiveness of the pigment particles.
Flowing out. The binder must be able to flow out and form a smooth, uniform film, which provides optimum film properties and allows good gloss by maximizing the reflection of light rays. Poor flow-out weakens film properties, distorting and dulling the film surface.

Providing the required physical properties. The binder must be chosen for the most desirable physical and chemical properties for an end use application. Important properties include:

- Hardness
- Flexibility
- Durability
- Recoatability
- Abrasion resistance
- Impact resistance
- Weather resistance
- Water resistance
- Heat resistance
- Sunlight resistance
- Hot/cold resistance
- Chemical resistance
- Corrosion resistance
- Detergent resistance
- Stain resistance

Various products require paint films that possess properties specific to that particular product. For example, automobiles and trucks require finishes that resist road salt, gasoline, oil, harsh chemicals, detergents, bird droppings, tree saps and acidic components in rain and air. Home appliances such as washing machines must have finishes that stand up to water, bleach and alkaline detergents. Machinery finishes must resist cleaning agents, heat-transfer fluids, cutting oils and various lubricants.

Pigments

Pigments are tiny solid particles that are used to enhance the appearance by providing color and/or improve the physical (functional) properties of the paint film. Pigments used to provide color generally range from 0.2 to 0.4 micron in diameter; functional pigments are typically 2 to 4 microns in diameter, but they may range as high as 50 microns. The pigments need to be permanently insoluble in the binder of the coating. If they were to dissolve, they could change the properties of the binder and lose their capability to provide a particular appearance enhancement and functional improvement.

Appearance Pigments

The classes of pigments that enhance appearance are white pigments, colored pigments and metallic powders and flakes. Examples of white pigments are antimony oxide, leaded zinc oxide, titanium dioxide (anatase and rutile), white lead and zinc oxide. Included in the category of white pigments are extender pigments, which can include barytes, bentonite, calcium carbonate, China clay, mica, silica and talc. The relatively low-cost extender pigments can be added in small percentages to reduce the amount of white pigment required.

Colored pigments are available in both inorganic and organic materials; other pigments are mostly inorganic. Inorganic pigments have a number of important
properties, including low water/organic solvent solubility and high ultraviolet light/thermal stability. Organic pigments are often used because of their visual purity, crispness and brilliance. Organic pigments have great liveliness and excitement when compared with inorganic pigments of the same color. They display none of the muddy overtones of the inorganic pigments.

Examples of colored pigments are phthalocyanine blue, cadmium yellow and orange, molybdate orange, chrome orange, toluidine red, cadmium red, phthalocyanine green, chrome green, black iron oxide, yellow iron oxide, red iron oxide and brown iron oxide. The colored pigments are often used in blends of two or more types to yield specific tints. Pigment materials containing cadmium, chromium and lead have increasingly been phased out of use because of their toxicity.

Examples of metallic pigments are aluminum and bronze flake (shown greatly magnified in Figure 3-2), which produce a sparkly effect by randomly reflecting light. The same effect can be achieved with mica-type nonmetallic pigments. The metallic pigments, due to their conductivity, tend to align themselves differently in a paint film when applied by electrostatic and nonelectrostatic techniques. The mica type do not have this characteristic because of their nonconductivity.

Functional Pigments

Zinc dust is an example of a functional pigment that is added to a binder in large amounts to improve corrosion resistance. The heavy concentration of zinc particles allows them to touch each other, providing continuous conductivity. The conductivity permits the zinc to provide sacrificial protection in the corrosion process, meaning that if the zinc-loaded paint film is scratched through to a steel
substrate, the zinc will corrode sacrificially in place of the steel. Some zinc-rich coatings may contain as much as 90 percent zinc.

The functional properties of a paint film affected by pigments can include adhesion, corrosion resistance, film strength, water resistance and gloss. The type of functional pigment selected for a particular paint formulation will depend on the required end use properties of the paint.

**Pigment Milling and Dispersion**

Pigments purchased by paint manufacturers tend to contain numerous tightly adhering clusters of particles. If not broken up, these agglomerates appear in the paint film as unsightly specks. The clusters are broken down into their original separate particles in a milling/dispersing process. The mill for this process consists of a container with a motor-driven fan-type blade that is shaped for optimum shearing and circulation of the material being milled. The material to be milled includes a precisely measured amount of binder and pigment.

In addition to breaking up pigment clusters, the milling/dispersing process has another function: to wet each pigment particle with binder. If pigment particles are not properly wetted and dispersed, clustering will result. Clustering reduces the effectiveness of the pigment particles, as shown in Figure 3-3. The maximum amount of pigment wetable by the binder is known as the critical pigment volume concentration (CPVC).

![Figure 3-3. Clustering of Pigment Particles Adversely Affects Paint Film Characteristics](image.png)

Decreasing or increasing the amount of pigment in a binder-pigment dispersion away from the CPVC will bring striking changes in the paint film properties. These changes can be graphed and will produce characteristic curves for each property. Each graph of pigment-to-volume concentration versus a particular paint
film property will show a distinctive change of direction at the CPVC, as shown in Figure 3-4.

Figure 3-4. Paint Film Characteristics Vs. Pigment Volume Concentration (PVC)

When the pigment loading in a paint is high, pigment particles can protrude from the applied paint film, creating a rough surface that scatters light, giving a low gloss. A low pigment concentration can leave a smooth paint film, resulting in a high gloss, as shown in Figure 3-5.

Figure 3-5. Light Diffusion From a High PVC Paint Reduces Surface Gloss
A solvent is a liquid that is able to lower the viscosity of a binder sufficiently to allow application onto a product and then evaporate to permit the formation of a paint film. The solvent’s function in paint is, therefore, transitory. It is a vital part of the liquid paint but leaves as the paint film solidifies or cross-links.

Solvents can be categorized into four types:

- Petroleum hydrocarbon solvents
- Chlorinated hydrocarbon solvents
- Oxygenated solvents
- Terpene solvents

**Petroleum hydrocarbon solvents.** This category consists of aliphatic (straight-chain) solvents and aromatic (containing benzene rings) solvents. Aliphatic solvents tend to be low in their ability to dissolve a resin. Examples of aliphatic solvents are mineral spirits and VM&P (varnish maker’s and painter’s) naphtha in a narrow boiling range fraction of petroleum with boiling points of about 93 to 149°C. Aromatic solvents, however, are high in solvent power. Only four aromatic solvents are commonly used in coatings: medium-flash aromatic naphtha, high-flash aromatic naphtha, toluene and xylene.

**Chlorinated hydrocarbon solvents.** Chlorinated hydrocarbon solvents are characterized by high solvent power, very fast evaporation rates and virtually no flash point (virtually non-flammable). Examples of chlorinated hydrocarbon solvents used in coatings are 1,1,1-trichloroethane and methylene chloride.

**Oxygenated solvents.** Oxygenated solvents have a range of solvent power, which can be adjusted to almost any value by blending various types of these solvents. The four types used in coatings include alcohols, esters, glycol ethers (and their acetates) and ketones.

**Terpene solvents.** Terpene solvents are derived from pine trees and are characterized by high solvent power. Common terpene solvent types are turpentine, dipentene and pine oil.

**Selecting a Solvent**

Chemists have devised many parameters for solvents, but the two most important for coatings are solvent power or solubility parameter and evaporation rate. The solvent power is the ability of a solvent to dissolve a binder. The many different types of solvents have various solvent powers, and the numerous classes of binders have different capabilities to be dissolved.

The evaporation rate of a solvent from paint is of crucial importance because the solvent needs to leave the paint at an ideal rate to allow the paint film to form properly. Solvents with fast evaporation rates include acetone, methyl alcohol, methyl ethyl ketone, ethyl acetate and lacquer diluent. Solvents with slow evaporation rates include ethylene glycol monobutyl ether acetate, diisobutyl ketone, amyl alcohol, mineral spirits and xylene. Interestingly, as shown in Figure 3-6, some “slow” solvents have slower evaporation rates than does water.
# Paint Components and Their Functions

## Properties of Common Solvents

<table>
<thead>
<tr>
<th>Solvent Type</th>
<th>Common Solvents</th>
<th>Lbs./Gal.</th>
<th>Evaporation Rate (BuAc = 1)</th>
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<tr>
<td>Allphatics</td>
<td>VM&amp;P Naptha</td>
<td>6.24</td>
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<td>Mineral Spirits</td>
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<td>Aromatics</td>
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<td></td>
<td>Xylo</td>
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<td>Aromatic 150</td>
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<td>Isopropanol (99%)</td>
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<td>Water</td>
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<td>0.36</td>
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</table>

*Figure 3-6. Properties of Common Solvents*
Solvents may be further classified as true or active solvents, diluents, reducers and thinners. A true solvent can dissolve and rapidly reduce the viscosity of a binder. Within limits, a diluent solvent is able to reduce viscosity, but it simultaneously weakens solvent power of the true solvent. Various solvents can function as true solvents or diluents, depending on the particular type of binder.

The terms “thinner” and “reducer” are inexact and refer to any volatile liquid used in mixing paints.

**Solvent As a Source of VOC Emissions**

In the early 1970s the Environmental Protection Agency (EPA) began to draft regulations to limit the amount of VOC emissions from coatings. Its main method of doing so was to force paint manufacturers to lower the solvent content of coatings. This trend is likely to intensify.

Various solvents, formerly termed “exempt” by the EPA, were permitted in paint formulations in nonregulated amounts. Solvent use, however, has become limited mainly to 1,1,1-trichloroethane. This solvent and exempt methylene chloride have been shown not to produce photochemical smog, but are sometimes undesirable for other reasons. Many believe that their use constitutes a significant long-term health hazard to workers exposed even to low vapor levels. Use of 1,1,1-trichloroethane will decline since its U.S. manufacture must end by the year 2005. Additionally, some EPA enforcement agencies do not consider them as exempt; some states ban their use as paint solvent. They are said to cause stratospheric ozone depletion.

A typical low-solids paint loses more than half of its volume as it changes from a wet film to a dry film due to evaporation of volatile solvents, as depicted in Figure 3-7. In addition to causing air pollution, this obviously is wasteful. The method of application determines to a large extent at what point the relative

![Figure 3-7. Effects of Solvent Evaporation](image)
amounts of solvent are driven out of the paint film. Far more is lost immediately after application in a spray process than in a dip or flow-coat application, for example.

**Additives**

Literally hundreds of chemicals can be added to paint batches (both liquid paint and powder) to improve the paint performance in a specific way. These additives are usually considered to be a distinct category of paint ingredients. Sometimes, however, an additive can also be a pigment. A unique type of binder can, in some instances, be considered to be an additive. Some additive types include:

- Antiblock agents
- Antifreeze
- Blending aids
- Curing agents
- Defoamers
- Flow control agents
- Gloss modifiers
- Softening agents
- Storage stabilizers
- Thixotropes
- UV stabilizers

**Antiblock agents.** These can be added so that parts can be stacked together soon after curing. Antiblock agents reduce the tendency for paint films to stick together when they are not quite fully cured.

**Antifreeze.** Waterborne emulsions can be ruined if they freeze. Antifreeze materials may be added to waterborne paints to reduce the likelihood of this occurring.

**Blending aids.** These are designed to increase the efficiency of paint manufacturing. Mixing aids such as dispersants, emulsifiers, surfactants, antifoams and related compounds help simplify production of paint by reducing mixing and blending times.

**Curing agents.** This group of additives can improve paint curing properties. These catalysts, driers or activators are used to increase binder cross-linking during enamel curing to speed handling, packaging and shipping of painted parts.

**Defoamers (antifoamers).** Foam eliminators are frequently necessary with waterborne emulsion paints. The emulsifiers tend to create foam on waterborne paints, just as oil emulsifying detergents will generate foam in dishwashers.

**Flow control agents.** These can ease paint application. Sag balancers, bodiers, flow-control additives (leveling agents) and thixotropes will affect the rheology (flow properties) and viscosity of wet paint films. Polyethylene oxide is used in waterborne paints to enhance atomization at low air pressures. Spraying with low air pressures reduces paint waste. Acrylic lacquers often contain cellulose acetate butyrate (CAB), which eases breakup into spray droplets and improves wet paint flow-out. CAB also holds the paint film "open" to reduce the tendency for solvent popping.
Gloss modifiers. Various additives can reduce gloss levels without affecting film strength if nongloss surfaces are desired.

Softening agents. These plasticizers can give flexibility to brittle binders such as those found in acrylic and vinyl lacquers. They act by increasing the freedom of movement of molecules under stress.

Storage stabilizers. Additives may be used by the paint manufacturer to increase paint storage stability. These additives will reduce the tendency of paints to skin over and can reduce pigment settling during storage. Stabilizers may also allow a uniform viscosity to be maintained for long periods.

Thixotropes. Thixotropes change a paint’s shear/viscosity relationship. A normal solution has the same viscosity at rest as it does when sheared (mixed). A thixotrope added to a paint will cause it to be viscous at rest and less viscous when pumped, sprayed or stirred, as shown in Figure 3-8.

UV stabilizers. This category of additives can increase a paint film’s resistance to ultraviolet (UV) light. Nearly all organic polymers are somewhat susceptible to attack and damage by exposure to UV light. Even natural protein polymers such as human skin can be harmed by sunlight. Frequent exposure to sunlight can damage skin due to breakdown of organic cellular materials. Skin pigments and sun screening lotions lessen this danger. Nonpigmented paint films lack sun-blocking protection. In nonpigmented coatings, such as spar varnish for marine use and automotive clearcoats, UV light protection is provided by screeners, quenchers or selective light-ray absorbers. UV light is very powerful and tends to degrade

![Figure 3-8. Paint's Shear/Viscosity Relationship](image-url)
exterior finishes on cars, boats and homes rapidly in sunny regions.

Other additives include antifloating agents, antimicrobial agents, antioxidants, antiskin agents, antistatic agents, catalysts, coupling agents, dispersants, driers, flame retardants, friction reducers, plasticizers and thickeners.
CHAPTER 4
Types of Paint

While paints could be categorized in many ways, it is probably most useful to segregate them into two major groups: 1) trade sale or consumer paints 2) industrial paints. Consumers typically buy paint at a major paint outlet or hardware store. The shelves of such stores are likely to carry paints that could fall into many classifications including:

- High-gloss
- Semigloss
- Flat
- Deck
- Marine
- Floor
- Oil-based
- Latex
- Varnish
- Shellac
- Lacquer
- House
- Trim
- Enamel
- Wall

Various ways could also be devised to categorize industrial paints. Generally, however, three distinct categories emerge based on:

- End use characteristics
- Binder category
- The paint’s physical makeup

**Industrial Paint Types According to End Use Characteristics**

This category identifies industrial paints according to their end use. The following are some examples:

- Primers
- Sealers
- Surfacers
- Basecoats
- Clearcoats
- Topcoats
- Maintenance coatings
- Concrete paints
- Wood finishes
- Marine finishes
- Peel coats
- Chemical agent resistant coatings
- Singlecoats
- Multicoats

**Primers**

A primer is a paint formulated to be applied, often directly, to a substrate and beneath another coating. A major function of primers is to promote lasting
adhesion of subsequent paint layers to the substrate. Often, a topcoat applied directly to a surface will not adhere sufficiently. By first applying a primer and then a topcoat, film durability is often enhanced. Another important function of a primer is to isolate the substrate from the effects of weather. This is, perhaps, of greatest importance for metal substrates due to the unsightly nature of their oxidation products. Figure 4-1 shows the basics of a corrosion process under a coat of paint.

![Corrosion diagram](image)

**Figure 4-1. How Corrosion Attacks a Paint Film**

The most significant types of primers include:

- **Wash (etch) primers**
- **Shopcoat primers**
- **Flash primers**
- **Bake (force-dry) primers**
- **Spray primers**
- **Electrocoat (E-coat) primers**.

**Wash (etch) primers.** Despite the name, wash (etch) primers do not perform a cleaning function. The name indicates that they are low in viscosity and provide only a very thin or “wash” coating of about 0.5 mil thickness. “Etch” means they are formulated to etch the surface. Wash primers are used to achieve good paint adhesion on metals that have not received a phosphate or chromate conversion coating. Most wash primers are manufactured as two-part systems that are mixed just prior to use.

Wash primers are formulated with an etchant such as phosphoric acid to attack and slightly roughen the surface, giving the wash-primer binder “teeth” for mechanical bonding. Wash primers most commonly have an acid-resistant vinyl
butyrate binder component and frequently contain anticorrosion pigments such as zinc chromate. The characteristic greenish-yellow color (or dark green) of many wash primers is due to the zinc chromate pigment.

Wash primers are intended for use on clean, bare metal—they are not normally applied over metal that has been phosphated or chromated. Although a conversion coating plus wash primer is required in some military specifications, it is not recommended. The acid should react with bare metal; it may not react and thus can cause blisters if applied over conversion coatings. Recently a few military specifications have been updated to omit a wash primer when the substrate is conversion-coated.

**Shopcoat primers.** These are usually considered to be temporary coatings of about 1 mil in thickness to protect metal products during outdoor storage. They are especially used on steel to prevent rusting and are often stripped off before the final painting of a product.

**Shopplate primers.** In ship-building, a shopplate primer is applied at the steel mill under carefully controlled conditions. This mill-applied coating is superior to primers that are applied to the steel hull under possible adverse weather conditions. Shopplate primers have excellent durability because the controlled mill environment enhances paint film quality. A shopplate primer is at times also called a shopcoat primer, or “weld-through” primers.

**Flash primers.** An air-dry primer is called a flash primer because the solvents evaporate or flash off.

**Bake (force-dry) primers.** A bake (force-dry) primer can be used if a paint would cure too slowly at ambient conditions. The cure time is considerably shortened by “forcing” the process with somewhat elevated temperatures. Forcing can occur with most air-dry paints and is not restricted to primers.

**Spray primers.** These can be various types of primers that are intended to be spray-applied.

**Electrocoat (E-coat) primers.** Electrocoat primers are applied using the same techniques as other E-coat paints. Depending on the formulation, a deposited E-coat may be considered to be a singlecoat.

### Sealers

The term “sealer” has separate meanings in different industries. In wood finishing, a sealer is applied over a stain. Wood sealers are used to close the pores of the wood, lock in the color of the stain and raise tiny wood fibers along the edges of the wood grain. Raising these fibers allows them to be sanded readily to produce a smooth surface. This step is crucial for fine-quality furniture finishing.

The function of sealers in metal finishing is quite different. The metal sealer may be used between a primer and the topcoat to prevent topcoat solvent
migration into the primer. Solvent migration from the topcoat could result in pigment leachout from the primer and discolor the topcoat. This phenomenon is called “bleeding” or “staining.” The leached-out pigment is especially noticeable with dark primers and light topcoats. Solvent migration can also cause swelling of the underlying paint layer, and solvent absorption occurring along fine sanding scratch lines of a paint layer can produce ridges that are visible through the topcoat. The ridges become magnified when they are painted over due to swelling from absorbed solvent. This defect is known as “sand-scratch swelling.”

Sealers are used to bridge across large differences in polarity between primer and topcoat, as shown in Figure 4-2. Such large polarity differences reduce bonding adhesion. A low-polarity epoxy E-coat paint can be bridged by a sealer so that a highly polar acrylic lacquer topcoat will adhere. If the acrylic were applied directly over the epoxy, loss of adhesion would readily occur. The situation is similar to the tendency for water to form beads on a waxed surface. Because of their mutual attraction, the highly polar molecules of water tend to pull themselves together into individual drops rather than adhere uniformly to the nonpolar waxed surface.
Surfacers

Surfacers are formulated to be readily sanded and are applied to provide a smooth base for a topcoat that must exhibit a high gloss. Smoothness is one of the characteristics of a coating with high gloss. These coatings are designed to be applied and cured, then sanded to level out minor roughness. Unless the surface is already smooth, surface sanding is required prior to applying high-gloss finishes. Few paints have enough flow to level out and fill surface irregularities completely. Paints are usually easier to sand than metals, but not all paints are suitable as surfacers. By the proper choice of resin and pigments, paints designed as surfacers are made easy to sand. Because sanding is slow and costly, surfacers are used only when necessary and then only on parts where the cost can be justified.

Basecoats

Any paint below the topcoat is a basecoat. The term also can refer to a pigmented (color) coat that will receive a clearcoat. The auto industry uses basecoat/clearcoat technology to enhance the brilliance of a finish. The basecoat provides the color; the clearcoat furnishes the shine.

Basecoat/clearcoat technology was developed by European auto manufacturers in an attempt to match the gloss of metallic finishes on cars produced in North America. In the 1970s North American cars were finished mostly with acrylic enamels and lacquers; European cars were finished mostly with alkyd melamine topcoats. The acrylic enamels and lacquers satisfactorily covered metallic flake added to the paint; the alkyd melamine tended to leave fragments of the flakes extending out of the paint, lowering the gloss.

The European car manufacturers, in cooperation with their paint suppliers, developed an unpigmented paint to solve this problem. When applied over the normally pigmented alkyd melamine metallic topcoats, the clearcoat effectively buried the metallic flake, creating a smooth paint surface. The smooth surface exhibited exceptionally high gloss. It was, in fact, noticeably higher in gloss than the North American topcoat acrylic finishes. Japanese car producers immediately adopted this clearcoat technology for their metallic finishes. North American auto manufacturers soon also adopted the basecoat/clearcoat technology.

Most automakers use clearcoats on both nonmetallic and metallic colors because of the high gloss they provide. Acrylic, polyester and urethane topcoat materials have been used for the base colorcoat and the clearcoat finishes. The film thicknesses on North American vehicles typically are 0.75 mil of metallic color basecoat plus approximately 1.4 to 1.6 mils clearcoat applied over it. Nonmetallic shades use more basecoat and slightly less clearcoat.

The latest development in low-VOC basecoat/clearcoat technology employs a thixotropic waterborne color basecoat that is dehydrated in a quick bake to remove
nearly 95% of the water. The waterborne color basecoat is then topcoated with a high-solids or a waterborne clearcoat. Best metallic appearance is achieved with color basecoats that have a large shrink factor, that is, paints that contain high percentages of volatile materials.

Since VOC restrictions negate the possibility of using organic solvents in large quantities, the method of choice must be to use a safe and nonpolluting solvent to achieve the necessary high film shrinkage. Since water is the only solvent that meets these criteria, waterborne colorbase technology has been perfected. Waterborne clearcoats further reduce VOC emissions.

Clearcoats

Clearcoats are defined as paints without pigments. Figure 4-3 shows a brass bed coated with a clearcoat to prevent tarnish. Figure 4-4 shows drawings of metal.

![Figure 4-3. Brass Bed Coated with Clearcoat](image-url)
flake projecting through the surface, reducing film gloss. A clearcoat applied over the projections would increase gloss. A clearcoat applied to wood is usually termed a varnish.

<table>
<thead>
<tr>
<th>FLAKES PROJECTING FROM THE PAINT SURFACE SCATTER LIGHT.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ALKYD-MELAMINES</strong></td>
</tr>
<tr>
<td>MORE FLAKE PROJECTION REDUCES FILM GLOSS</td>
</tr>
</tbody>
</table>

| **ACRYLICS**                                           |
| WITHOUT A CLEARCOAT THE ACRYLICS HAVE SUPERIOR GLOSS |

Figure 4-4. Typical Metal Flake Orientation Patterns

Topcoats

The topcoat's function is to provide a pleasing appearance to the surface it covers. The gloss of a topcoat may vary from none for a photographic darkroom paint to the very high gloss of a bicycle paint. Figure 4-5 shows a photomicrograph cross-section of a topcoat and primer. Finely ground pigments in the topcoat enhance topcoat gloss.

Topcoats must also exhibit the proper shade and intensity of color. The topcoat, being the most exposed surface, also needs to protect the surface during exposure to the normal service environment. This might require a particular ability to fight abrasion, withstand sunlight, resist attack by chemicals or be durable under special exposure conditions.

Maintenance Coatings

Considerable amounts of paint are applied onto objects that are immobile or too large to allow force-curing in an oven. Maintenance paints make up an extensive and varied group that is used in exceptionally large volumes each year. In addition, maintenance coatings are without exception air-dry paints. Examples of their use are traffic-lane markings on roads and parking lots, the interior and exterior of industrial buildings, large mechanical equipment and highway bridges. Most
maintenance paints are purchased directly from the paint manufacturer through large commercial accounts.

**Trade Sales Coatings**

These are air-dry paints sold mostly by retail stores to individual homeowners, apartment dwellers and home or office painting contractors for residential and commercial decorating of interior and exterior surfaces.

**Concrete Paints**

Some paints are formulated especially for concrete. They must be extremely durable to withstand exterior exposure.
Types of Paint

Wood Finishes

These are coatings formulated for wood. They include fillers, stains, toners, varnishes, sealers and lacquers.

Marine Finishes

Coatings used in a marine (water) environment must have extraordinary resistance to water and humidity. They are applied to boats, docks and other sea or shore uses.

Peel Coats

Peel coats are designed for easy removal and are typically applied to surfaces that require frequent cleaning. The interiors of paint booths, for example, are often protected with this type of coating. After a period of use the coating can be peeled off, removing all the accumulated overspray and any accumulated dirt along with it. The surface is given a new peel coat immediately after the old one is removed, allowing fast and easy periodic cleaning of the surface.

Surplus military ships, tanks, helicopters, howitzers and similar items are protected during long outdoor storage with these peelable coatings. “Mothballing” in this fashion combines a sheltered storage condition with easy removal for quick reactivation of the equipment when needed.

Chemical Agent Resistant Coatings

These were developed for military vehicles and equipment to permit ready decontamination in case of chemical, biological or nuclear incidents. They are formulated to resist strong decontaminant chemicals.

Other Paint and Coating Classifications

Singlecoat

The term singlecoat indicates that only one coat of paint is used. The coating must be able to perform all of the functions expected of the paint on a particular product. The paint might be expected, for example, to have an attractive color and to resist marring and scratching. Because one specific paint is rarely able to perform various coating functions adequately, separate paints have been developed that can be formulated for individual performance requirements.

Multicoats

This term applies to two or more coatings applied to a surface. Often the
performance of all of the functions required of a paint is beyond the capabilities of a single formulation. The first coat may be an alkyd primer, followed by a modified acrylic surfacer for the second coat. The topcoat could be a urethane material. Each paint type has its own special function(s) to perform. By using several different formulations, the overall paint system has far better performance than could be achieved by any one coating material alone.

**Paint Types According to Binder Category**

It makes sense to name a paint after the category of binder because the binder is the heart of the paint. The chemistry of a binder gives it and the formulated paint specific properties. For example, the hardness and flexibility of a dry paint film vary according to the type of binder in the paint and with the average size and the size distribution range of the resin molecules in a given paint batch. Figure 4-6 shows molecular weight distribution curves and how a narrow curve is indicative of improved paint properties. Figure 4-7 depicts how paint film properties will vary according to the film’s softness or hardness.

Stating that a paint is, for example, an acrylic, reveals a great deal about the paint. The paint will have the characteristics of an acrylic resin, modified somewhat by the pigmentation and additives.

Both resins have an average molecular weight of 27,000. Resin A will have superior paint properties.

*Figure 4-6. Molecular Weight Distribution Curves*
Figure 4-7. Resin Soft-to-Hard Ranges and Related Properties

Many types of film-forming resins are used as binders. The following is a list of some of the major types:
- Acrylics
- Alkyds
- Cellulosics
- Epoxies
- Halogenateds
- Oleoresinous (oil-based)
- Phenolics
- Polyesters
- Silicones
- Urethanes
- Vinlys

Acrylics
Acrylic binders are able to achieve a high gloss and form hard, highly weatherable surfaces. The hardness of acrylics contributes to good abrasion resistance and increases durability. Acrylic resins are above average in cost. They have very good heat stability and excellent chemical and ultraviolet light resistance. Nearly all trucks and cars produced in North America from about 1950 through 1989 received either acrylic lacquer or enamel topcoats because of these strong performance properties. Paints with hard surfaces have maximum abrasion resistance, but if they are too hard they also tend to be brittle. This can result in rapid chip formation from bumps and related impacts.

Alkyds
This family of resins is widely used because it is so varied; each can be cross-formulated with many different binder chemicals. In this way it is possible to produce paints with an enormous variety of specific performance properties.
Alkyds come close to being ‘the general purpose paint’ because of their good overall properties plus their moderate cost. Alkyds are chemically modified vegetable (plant) oils, especially soya and linseed oils. Because they incorporate drying (air-drying) oils, they are often used to produce ambient-cure paints. This is an important factor in why alkyds are one of the most heavily used paint resins. The carbon-carbon unsaturated intramolecular bonds (double bonds) in alkyds (and in all drying oils) react with oxygen in the air to produce fully cured finishes. Alkyds are the major resins used in combination with others to introduce air-dry capability in a paint formulation. They can also be force-cured and formulated into baking finishes.

Alkyds can be modified with various chemicals to increase specific properties. Styrenated alkyds, for example, have increased chemical resistance compared with pure alkyds. Alkyd melamine resins give durable finishes with excellent weatherability, but they are considerably higher in cost than some alkyds. The alkyd-melamine finishes are normally employed only in baking finishes.

**Cellulosics**

These inexpensive materials are produced by the reaction of nitric acid with cellulose, which forms nitrocellulose lacquer resins. These are limited in solubility, tend to be brittle and have quite poor heat resistance. They tend to be used because they are relatively low in cost. Although they have poor to fair chemical resistance, cellulosics are attractive for use in low-priced, quick-drying lacquers. They are sometimes used in strippable coatings. Because of their limited durability and high solvent content, they are now not widely used in industrial painting. Nitrocellulose lacquers were first used for automotive topcoats in 1928 because they air-dried in “hours.” This made them more efficient than the oil-based paints that had been used and required a full week to cure.

**Epoxies**

The epoxy resins are produced by the reaction of epichlorohydrin with bisphenols. They have excellent water resistance and one of the highest resistances to attack by alkali of any commercial resin. They form hard, tough, salt- and water-resistant coatings and exhibit superior chemical resistance as well. Their excellent heat and abrasion resistance makes them ideal candidates for primers. They are one of the best metal primer resins that can be used in industrial applications. The epoxies are somewhat costly. All one-part enamel epoxies require baking; many formulations require substantial oven times and temperatures.

Two-part epoxies produce equally durable finishes and have an added advantage over one-part epoxy resins. Two-part epoxy paints can be used for ambient-temperature curing when it is impossible to bake the part. This capability is especially valuable in fields such as the marine industry where extreme corrosion resistance is required and painting must be done under any weather conditions...
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during all four seasons of the year.

The major weakness of epoxies is their tendency to chalk when exposed to ultraviolet light. This chalking contributes to loss of gloss but is rarely extreme enough to interfere with the structural integrity of the coating. Epoxies should not be used where appearance is critical. They are ideal paint resins wherever excellent corrosion resistance and strong chemical resistance are important. Large-scale industrial use of epoxies is directly attributable to their outstanding protective qualities. Because of their strong resistance to degradation by alkali, epoxies are frequently used in primers for steel and other metals.

Halogenated Resins

Fluorocarbons and chlorinated rubber binders are employed in the formulation of superior long-term weather-resistant maintenance coatings. They are expensive, often very difficult to apply and have relatively low heat resistance. Their chief virtue is their ability to be used in harsh climatic environments and provide up to 30 or 40 years of reliable service. Halogenated resins are used to decorate and protect exterior surfaces of metal panels and similar decorative structural members in architectural construction. Large, modern office buildings use components coated with these resins for striking visual effects.

Oleoresinous (Oil-Based) Coatings

Oleoresins are some of the oldest binders used to make coatings, but these low-cost resins can still be used to make good paints. Although they dry slowly, drying agents can be added to speed curing. Driers (or catalysts) are frequently salts of lead, cobalt and manganese. The drying oils (linseed, soya, tung, castor, cottonseed, etc.) form the basis for these binders. They are often modified with synthetic resins to improve drying time or to increase ultimate hardness. Drying oils are sometimes mixed with alkyds to reduce paint costs for noncritical applications.

Phenolics

Paints and varnishes made with these resins tend to be very hard and somewhat brittle but extremely resistant to stain, solvent and acids. They are often used for coatings on copper wire and windings for motors and transformers. They are not good for decorative finishes. The aromatic structure of the molecules causes phenolics to turn yellow or brown in sunlight, although they have been used for dark marine-varnish finishes. Their acid resistance makes them a good choice for many food can linings.

Polyesters

Polyesters are much like the alkyds in chemical structure and can be used for various coating types. They are also moderate in cost. Polyesters do not have
unsaturated linkages as do the alkyds. For this reason they sometimes are called the “oil-free” alkyds. They do not air-dry and are available only as baking finishes. Polyesters have found extensive application as powder coatings since the early 1980s. They are tough and durable in outdoor exposure and exhibit good flexibility and excellent hardness in both wet and powder coatings. Two major polyester powder coatings are being used: isocyanate cross-linked and TGIC (triglycidyl isocyanurate) cross-linked. The isocyanate cross-linked powders provide an attractive but slightly less durable finish than the TGIC cross-linked systems. The TGIC powder coatings have outstanding exterior durability.

Silicones
Silicone (organo-silicone) resins have superior resistance to water, sunlight and all other normal exterior surface conditions. They do not chalk. Their most significant attribute, however, is high heat stability, which permits silicone paints to be used wherever conventional organic resin coatings would deteriorate rapidly. Although some are more heat-resistant than others, all organic resins will degrade

<table>
<thead>
<tr>
<th>Type</th>
<th>Properties and Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylics</td>
<td>• Excellent weather resistance</td>
</tr>
<tr>
<td></td>
<td>• Chemical resistance</td>
</tr>
<tr>
<td></td>
<td>• High heat stability</td>
</tr>
<tr>
<td></td>
<td>• Above average cost</td>
</tr>
<tr>
<td></td>
<td>• Hard, abrasion resistant</td>
</tr>
<tr>
<td></td>
<td>• Slightly brittle</td>
</tr>
<tr>
<td>Alkyds</td>
<td>• Very good overall properties</td>
</tr>
<tr>
<td></td>
<td>• Average cost</td>
</tr>
<tr>
<td></td>
<td>• Air dry curing</td>
</tr>
<tr>
<td></td>
<td>• Extremely heavy use in paints due to their fine performance</td>
</tr>
<tr>
<td></td>
<td>• Formulation widely variable</td>
</tr>
<tr>
<td>Epoxies</td>
<td>• Outstanding water resistance</td>
</tr>
<tr>
<td></td>
<td>• Tough, heat and abrasion resistant</td>
</tr>
<tr>
<td></td>
<td>• High alkali resistance</td>
</tr>
<tr>
<td></td>
<td>• Above average cost</td>
</tr>
<tr>
<td></td>
<td>• Chalking in sunlight</td>
</tr>
<tr>
<td>Urethanes</td>
<td>• Superior overall properties</td>
</tr>
<tr>
<td></td>
<td>• Excellent mar resistance</td>
</tr>
<tr>
<td></td>
<td>• Flexible, with high gloss possible</td>
</tr>
<tr>
<td></td>
<td>• Outstanding durability</td>
</tr>
<tr>
<td></td>
<td>• Relatively high cost</td>
</tr>
</tbody>
</table>

Figure 4-8. Comparison of Paint Resin Properties
in sustained heat of 500°F or higher. Silicone resin paints are used for applications such as motorcycle mufflers to withstand 900 to 1200°F. Some can withstand 2500°F and are used to mark identification codes on the heat-tiles of space shuttles. When these paints reach their use temperatures, the organic portions of the resins oxidize away. This leaves an essentially ceramic coating that is stable at elevated temperatures.

Silicones are also used at ordinary temperatures when blended with acrylics or alkyls for finishes that have unequalled weatherability and chemical resistance. The high-heat-resistant silicone paints require long curing times at temperatures of 650°F and above.

Urethanes

Among the most outstanding resins in paint usage are the urethanes because of their ability to combine gloss and flexibility with great chemical and stain resistance. Figure 4-9 compares the properties of urethanes with those of acrylics, alkyls and epoxies. Their cost is two to five times that of other paints, but they are unique in their amazingly high gloss levels throughout a wide flexibility range. Urethanes make ideal high-solids coatings that require little if any additional heat for curing. For coating heat-sensitive substrates with a low-solvent-content paint, urethanes are often the materials of choice. They are physically durable and show excellent water and weather resistance.

At least six types of urethane paints are possible, but two-part urethanes (polyol and isocyanate) have the best film properties. Prereacted (one-part) urethanes are sometimes used to form a blend with other resins. The advantage of prereacted urethanes is that no potentially toxic isocyanates are present.

A urethane is formed when an isocyanate chemically reacts with an alcohol. Unreacted isocyanates can cause respiratory problems if persons breathe their vapors for extended periods. Approved charcoal-cartridge filter masks or head shrouds with a separate air supply are recommended for persons applying two-part urethanes. No filter or cartridge masks are approved by the Occupational Safety and Health Administration (OSHA) or the National Institute of Safety and Health (NIOSH). To gain OSHA or NIOSH approval, the mask wearer must be able to detect any possible malfunction of the device. Since isocyanates have no recognizable odor, and no fail-safe indicator is available to reveal when a cartridge is spent, face masks cannot be approved for use when applying isocyanate-containing paints. Another problem with masks is that facial hair prevents a tight fit; bearded mask wearers may not be adequately protected, even when a mask is worn.

Recently introduced isocyanate-free urethane-type paints, which are for all purposes nearly identical in performance to isocyanate-containing urethane coatings, are considerably safer. A chemical variation of the epoxy linkage is used
to cross-link these systems. Because they have outstanding properties, urethanes are used where their flexibility, superior performance and durability can justify the high coating cost.

**Vinyls**

These resins can be rather rigid, or they can be heavily plasticized to achieve great flexibility if desired. Vinyls tend to be low in cost yet have extraordinary acid resistance. They have outstanding water resistance as well, which makes them a frequent choice for maintenance coatings. Their exterior durability is excellent, although vinyls tend to degrade in heat. For applications in wet environments such as offshore oil rigs, as shown in Figure 4-9, vinyls make excellent coatings. Polyvinylchloride (PVC) coatings are extensively used as can linings. Solution vinyl coatings find frequent use also in peel coats for spray booth maintenance.

For structural wood finishes where moisture must be allowed to escape from the building interior, polyvinylacetate is frequently used because it is porous enough to

![Figure 4-9. Air Dry Vinyl Resins Are Used in Wet Environments Such as This Offshore Oil Rig](image-url)
allow the water vapor to “breathe” through the film. This avoids the blistering that frequently occurs on wood siding when a nonporous paint traps moisture under the film. The water vapor pressure lifts the paint off the surface and either blisters or ruptures the paint film.

Resin Mixtures
Mixtures of binder resins are possible both within a resin family and in combination with other resin groups. Various acrylic resins are available for the formulation of an acrylic paint, or various vinyl materials can be used in the manufacture of a vinyl paint, for example. But interfamily resin mixtures are also used to produce cost-effective products or to fit a special performance requirement. Thus a coating formulation may contain an “epoxy-polyester” or a “vinyl-alkyd” binder. A paint may have a polymer blend containing any number of compatible binders.

Paint Types According to Physical Makeup
The third major way to classify a paint is according to its physical makeup. Sometimes the physical makeup differences are obvious, and sometimes they are not. The physical makeup of a “two-component” paint, for example, is obvious; it comes in two containers that are mixed together before application. Another paint with an obvious physical makeup is a metallic coating.

Sometimes the differences in physical makeup are not as obvious. Consider the terms solventborne and waterborne. A solventborne paint uses a traditional solvent to disperse the binder, pigment and additives, and a waterborne paint uses mostly water. Note that the terms are solvent(borne) and water(borne) instead of solvent(based) and water(based). The term “borne” merely implies “intimate involvement with,” as in the expression “airborne,” which means to be in air. The term “base” refers to the binder. A paint is acrylic-based, epoxy-based, alkyd-based, etc. Thus, a solventborne or waterborne paint can be acrylic-based, etc.

Fluidization Methods
A less obvious physical property of paint is the method of fluidization. The term fluidization refers to how the paint solids are fluidized. Paints can be classified into three major fluidization types: solutions, dispersions and emulsions, as shown in Figure 4-10. In Figure 4-11, their viscosity and percent solids are compared.

Solutions. In a solution paint each molecule of resin is dissolved in the solvent. The individual molecules are essentially floating in a large sea of solvent. As increasing amounts of paint resin are added, the viscosity continues to rise proportionally. This occurs because the long thread-like resin molecules physically intertangle with each other. The entwined molecules resist flow and thicken the paint. It is desirable to minimize solvent use, but this would excessively increase the viscosity. The answer to producing a high-solids paint is not simply to withhold
**SOLUTION PAINT**

Individual separate molecules.

**DISPERSION PAINT**

Small "clustered" groups of 10-25 molecules.

**EMULSION PAINT**

Large "clustered" groups of 50-75 molecules, each coated with a layer of emulsifying agent.

Figure 4-10. Major Resin Fluidization Methods

solvent; this creates a thick paint that would be difficult or impossible to apply.

**Dispersion**. One way to lower solvent use is with a resin dispersion. A resin uses a blend of solvents with low polarities that force resin molecules into a mild clumping or aggregation. A dispersion paint can force resin molecules to cluster into small nodules containing 10 to 25 molecules. The viscosity curve for a dispersion paint has a long plateau region into the high-solids range. Viscosity rises rapidly when the concentration gets so high that individual nodules of resin contact each other and begin tangling. The advantage of a dispersion is a reduction in the amount of solvent needed. It produces a paint with a higher solids content at a given viscosity as compared with a solution paint.

**Emulsions**. Producing even larger nodules with perhaps 50 to 100 molecules in each cluster would allow formulation of paints with even less solvent. The difficulty is that dispersion technology cannot be extended quite that far. Resin nodules of that size very rapidly agglomerate and produce a second layer.

The situation is similar to shaking a vegetable dressing with a salad oil and vinegar dressing. Vigorous shaking produces only temporary blending. After standing for just a short time, the oil floats to the top again. Many years ago condiment manufacturers discovered that one can cause permanent blending of oil and water if the oil particles are coated with a thin protein layer. The addition of egg to a salad oil-water mixture (plus a few spices) followed by vigorous blending produces mayonnaise. The separate oil and water phases of this seemingly single-phase product are visible with a microscope.
The egg protein coating on the salad oil droplets is called an “emulsifier.” Although neither protein nor egg is used, emulsion paints are manufactured in a similar fashion. In this case the emulsifier surrounds the paint resin nodules to prevent forming separation layers. Emulsion technology can produce coatings with higher solids than dispersion technology.

Both dispersions and emulsions can be produced in solventborne or in waterborne formulations. Wall paint for room interiors and house paint for exterior use are nearly all waterborne emulsions. These are often called “latex” paints. Latex does not imply that the paints contain natural or synthetic rubber-like resins. Latex is a chemical term indicating a waterborne emulsion of organic polymer. For this reason household paints are often labeled and advertised as being “latex” paints. The sap from a rubber tree is a naturally occurring waterborne emulsion and hence was called latex. The most significant thing about latexes (latices) is that they use water to fluidize materials that inherently are not mobile fluids and have virtually no water solubility.

An example of this is butter solubilized in water. Cow’s milk contains on the average about 12% cream. Cream, the major source of dairy butter, behaves as if it were a single-phase liquid. However, when churned, cream separates into clumps of butter and a watery residue called buttermilk. During churning, a protein emulsifier coating is rubbed off the butter particles, permitting the butterfat globules to join together on contact. They will form a large chunk of butter separate from the watery phase. Trying to reverse the process is difficult to
accomplish, yet that is essentially what is done in the manufacture of latex emulsion paints.

Emulsion paint manufacturing requires an emulsifier to stabilize the mixture of water and resin. Dispersions differ in that the resin clumps are small and do not require added emulsifiers to form a stable fluid mixture. Vigorous physical mixing alone is employed to form the dispersion.

Lacquers

Lacquers are paints containing binders with large organic molecules that are fully polymerized before they are applied. After the lacquers are applied and cured, their binders can be softened by heat or solvent. This allows lacquer paint films to be readily spot-repaired. Heat will reflow the binder in the paint film and remove minor scratch lines from repair sanding.

Solvent application to a cured lacquer paint film can dissolve the binder. This facilitates firm bonding between the film being repaired and a newly applied lacquer repair coat. Hot solvent vapor reflow has also been used for lacquers. This procedure employs an oven or a methylene chloride vapor gun to achieve a smooth paint surface with minimal hand polishing and no respraying of the sanded item. Reflow is low in cost and fast compared to manual polishing or respraying.

Lacquer molecules must be highly polar to achieve sufficiently hard and physically durable films. Dipole-dipole (magnet-like) bonds attract and hold lacquer molecules together firmly in the dry paint film. Lacquers are often easy to spray without producing runs or sags. Because lacquers form a hard film, they tend to experience chip damage.

Lacquer paint films cure through solvent evaporation alone.

The preparation of lacquers requires a considerable amount of solvent. The large binder molecules need aggressive solvents with strong dissolving properties, oxygenated solvents such as ketones, alcohols and esters. These solvents cause lacquers to tend to attack a paint film such as an enamel, causing blistering and wrinkling.

Enamels

Enamel paints contain resin molecules that are unpolymerized or only partially polymerized. Enamel molecules chemically link together after the paint has been applied. Fully cured enamels are to a degree thermosetting due to the additional chemical cross-linking that occurs among the molecules after the coating has been applied. Sufficient cross-linking must take place to provide the requisite hardness and water resistance to the film, however, the extent of cross-linking in enamels is normally only moderate. If too much cross-linking takes place, the paint film becomes overly hard and brittle with poor chip resistance (low impact strength).

Enamel curing begins to take place rapidly when the solvent evaporates and cross-linking is activated by heat or radiation. The resin links together in many
places along the molecule chains by irreversible chemical reactions. If solvent evaporation alone took place with enamels, a soft, gummy film would result.

Resin molecule cross-linking takes place by a number of mechanisms. Binders may cross-link by reaction with the oxygen in the air. Alkyds and oil-based coatings cure this way. Other enamels may react with moisture in the air and undergo subsequent chemical reaction. Most frequently the molecules undergo self-reaction of chemical groups present within the resin. These reactions occur rapidly only after appreciable amounts of the solvents have evaporated and the molecules are in close proximity to each other. Even if molecules are near physically, they must be energetically activated or they will not cross-link. Depending upon their chemical properties, resin molecules may be selected that will be activated by means such as heat from a curing oven or by energy absorption from infrared radiation, ultraviolet light or electron beam rays.

The chemical bonds that are formed thus convert the soft, easily deformed resin into a firm, dry paint film. The paint formulator can chemically modify resins to produce a soft, flexible film; a hard, highly cross-linked film; or something intermediate, depending on which type of film is most appropriate.

Low-cost hydrocarbon solvents can be used in enamels. The short, small molecules of enamel binders dissolve readily with small amounts of solvent. The mild solvents used in enamels rarely adversely affect other paint films.

Enamel paint films are generally not so extensively cross-linked that they become brittle or able to resist being softened by many solvents. But they are sufficiently thermoset so that, unlike lacquer paints, they cannot truly be redissolved by solvents or be extensively softened with the application of heat.

A lasting repair on enamels usually must include repainting an entire panel. Spot repair of enamels is sometimes performed, even on some high-priced items, but it is not recommended. Enamel spot repair is always inferior to repainting an entire panel. Reflow enamels have been attempted but have not been successful.
Chapter 5

Low-Solids Coatings

“Low-solids” coatings are characterized as having a low percentage of solids and a high percentage of volatiles (solvent). While waterborne coatings tend to be low in solids they are not considered to be low-solids coatings. The term low-solids coatings refers only to low-solids solventborne coatings (LSSC).

A chapter on low-solids coatings is important to serve as a building block for the following chapter on high-solids coatings. The chemistry of these two coatings systems is considerably different.

Low-solids coatings have been made and used for a long time. Their formulation and use, however, multiplied greatly after the beginning of the petroleum industry in the 19th century. As the pumping of oil increased, numerous solvents and binders began to be developed. Coatings were formulated for thousands of products and paint companies sprang up almost everywhere.

The common denominator of these late 19th- and early 20th-century paint companies was the manufacture of coatings that contained relatively little solids and large quantities of solvents, because solvent was so cheap and environmental controls unheard of. The solvent was a convenient and inexpensive means of serving as a medium for the binder, pigment and additives.

Changes in Technology

The history of low-solids coatings is the general story of paints until 1966. In 1966 the first U.S. environmental regulation was adopted limiting solvent emissions. That year marked a major turning point in the history of paint.

In its early days paintmaking was not a scientific endeavor, and the craft evolved by trial and error. Paintmaking today, on the other hand, is a precise science engaged in by chemical professionals. In the early days of paintmaking, almost anyone could make a paint and prosper—provided one had a flair for marketing.
Today only qualified chemists can make paint. It would be far from accurate to state that before 1966 all paints were inferior. But one probably could say with some accuracy that in the early 20th century, the integrity of many paints was in question. Because early paintmakers were not chemical formulators, their products were often mixtures hastily put-together by technicians.

However, as time went by and hundreds of paint companies sprang up, the chemical integrity of the coatings began to improve. The chemical improvements went hand in hand with developments in the industrial revolution and with improvements in the mass educational system. As more chemists became available, the paint companies began to hire them, especially those companies with a vision that foresaw the day coming when paints would have to measure up as a quality product.

By the 1920s paint integrity was beginning to be established. This integrity improved steadily right up to 1966. But it by and large was a finessing of the LSSCs. Patents were being filed during this period that departed from the typical low-solids technology, but solvents continued to be so cheap that low-solids paints remained as the most practical coating for most products.

Until 1966, solvent use for paints soared. This large-scale use continued into the early 1970s by sheer momentum but then began to decline due to tightening solvent emission regulations and the Arab oil embargo.

These two forces precipitated a crisis in paintmaking. Solvent use began to be restricted through environmental regulations. At the same time solvent cost began to rise due to the oil shortage. In other words, solvent became a “bad” word in paintmaking.

Not all of the low-solids coatings made prior to 1966 were of poor quality, many were excellent. Almost everything that was painted was being finished with these coatings. These were the coatings that were applied to cars, appliances, airplanes, furniture—and to most other products. However, the solids content of these coatings was extremely low, and the solvent content was very high. Lacquers were still in wide use with a volume solids content of 10% and less and a solvent content of 90% and more; most of the industrial coatings by 1966 probably averaged around 20 to 30% in solids content.

Some paintmakers were trying to market coatings with higher solids content. But the market forces, namely the low cost of solvent, were not ripe for the successful marketing. Solvents were just too cheap. No market force was present to serve as a catalyst to change the technology.

**Coatings Industry Regulations**

When regulations limiting solvent emissions began to emerge in the 1970s, the coatings industry was caught almost totally off guard. National seminars began to be held annually in the mid-1970s dealing with high-solids and waterborne
Low-Solids Coatings

coatings. Formulators flocked to these meetings to learn how to make coatings that would comply with EPA regulations. A turning point in the painting industry had arrived. Marketing projections for low-solids coatings began to turn downward, and those for compliant coatings began to rise.

Most emission regulations now allow low-solids coatings use only if the solvent vapors are either destroyed by incineration or recovered through carbon adsorption. Low-solids coatings use in the future will likely be limited to companies large enough to be able to afford either incineration or carbon adsorption systems, or to companies too small in size to be covered by emission regulations.
High-solids coatings can be considered to be any coating that is high in solids or low in volatiles. Powder coatings are certainly “high-solids” because they are practically 100 percent solids. Because powder coatings are a separate class however, they will not be considered in this chapter. Waterborne coatings of all types, whether high or low in solids, will also be considered in another chapter because they too are considered to be a separate class of coatings.

The term high-solids coatings, then, can broadly include powder coatings, radiation cure coatings and, under some circumstances, waterborne coatings. In this book, however, high solids will refer only to high-solids solventborne coatings.

Some confusion exists among paint formulators and finishers as to what the solids percentage must be to qualify a paint as a high solids coating. Most in the coatings industry consider that if it is applied at 50 percent solids or higher a coating can be classed as high-solids. This book will follow that general consensus.

Recognizing the difficulty of defining a high solids coating, some prefer to call a solventborne coating of considerable solids as being one of “higher” solids. The term “higher” presents another problem: higher than what?

Most high solids coatings—as applied—typically fall into the range of 50 to 70 percent solids. A few 100 percent solids coatings are used in radiation cure finishing, but very few paints are employed in general manufacturing that are much above 70 percent solids as applied.

High-Solids Binders

Usable high solids coatings cannot be produced simply by increasing the solids content in a paint formulation. Remember that fluid viscosity rises rapidly as the percent solids increases in solution-type paints. Only by altering the chemical nature of the binders is it possible to produce a high solids coating that has a
viscosity low enough for normal application. The key difference is that low-
molecular-weight resins must be used to produce high solids coatings. Chemically
reactive short resin molecules at a low polymerization level are used in the
formulation. The fluidity of resins increases as the molecule size is reduced. Short
molecule chains do not intertwine as extensively, nor do they entangle and ensnare
each other as much as long molecule chains used in low solids binders. Thus the
relative movement throughout the solution is freer and easier with short molecules.

But merely using short molecule resin binders is not the complete answer. Small,
short molecules would not give the same extent of cross-linking during paint
curing. Soft and far less water- and abrasion-resistant paint films would result.
Since the properties of high solids coatings must at least be equal to those of the
low-solids coatings they are designed to replace, further modification of the small
resin molecules is necessary. Increased numbers of reactive sites for cross-linking
must be chemically added to these short molecules. This allows the overall film
properties to reach the same performance levels achieved with comparable low-
solids coatings.

The short resin molecules in high solids coatings can make VOC (volatile
organic compound) calculations difficult. Some of the short resin molecules may
volatilize when the paint is baked. The Environmental Protection Agency (EPA)
in New York found that several high solids coatings were being sold by their
manufacturers as 70 percent solids by weight. This was based on the assumption
that only the solvent portion of the formulation was volatile. In actual tests the
EPA determined the weight solids to be only 58.4 percent. This is not a minor
discrepancy, nor is it an isolated instance. A number of other paints tested ranged
anywhere from 2.0 to 9.4 percent lower in weight solids than the information on
the paint manufacturer’s product data sheets. If resins are not carefully checked,
they may contain low-molecular-weight molecules that will contribute to VOC
emissions. To prevent resin volatilization, the molecules should be reactive enough
to become part of the film or else be of sufficient size not to evaporate at oven
temperatures.

The leading resin types in high solids coatings are alkyds, polyesters, epoxies,
urethanes and acrylics. However, nearly any resin type can be made into a high
solids formulation, with the appropriate chemistry.

**Surface Tension**

An unfortunate consequence of increasing the number of cross-linkable reactive
sites along the length of these short high-solids resin molecules is that they produce
paints with a relatively high polarity and high surface tension (as measured in
dynes/cm). This can cause excessive Faraday cage problems during electrostatic
application. Some adjustment in the formulation is necessary to compensate for
the high surface tension problems. Normally paint formulators strive for low surface tension. Paints with high surface tension are characterized by a tendency toward increased cohesiveness. This makes it difficult to atomize the coating and increases the tendency to form fisheyes and related defects.

Surface tension for fluids is defined as the energy needed to generate an area of interfacial surface between the liquid and the air around it. The surface tension of liquid coatings is critical because it must be lower than the surface tension of the substrate it is to cover. To adhere fully and “wet out” various substrates, the paint needs to be as low as possible in surface tension. This is especially true when coating plastics, which as a group are low in surface tension and therefore somewhat low in wettability.

The sprayability of paints is more closely related to their surface tension and cohesiveness than to their viscosity. However, surface tension and cohesiveness are not conveniently measurable, but viscosity is readily determined with cup viscometers. Therefore, coating viscosity is commonly used as an indicator of sprayability. The lower the surface tension and viscosity the greater the ease of sprayability because paint is atomized with less energy when surface tension and viscosity are low.

Each component in a paint contributes to the overall surface tension and sprayability of the coating. Solvents have the lowest surface tension of all components, ranging from about 17.5 to 35 dynes/cm, and therefore tend to improve sprayability. However, high-solids coatings contain less solvent than low-solids coatings, which tends to lower the sprayability of high-solids coatings. In addition, high-solids coatings usually contain mostly slow-evaporating solvents, which tend to have relatively high surface tensions, further lowering the sprayability of high-solids coatings.

The resins used in high-solids coatings also contribute to the tendency for high-solids coatings to have poor sprayability. High-solids coatings resins are more reactive than those used in low-solids coatings and therefore have higher surface tensions. The surface tension of resins generally vary from about 35 to 60 dynes/cm.

Because paint viscosity tends to decrease with temperature, high-solids coatings are often heated prior to application to lower viscosity and therefore improve sprayability.

**High Solids Advantages**

The most pronounced advantage of high solids coatings is the reduced VOC emissions and the resultant improvement in compliance with state and local regulations. Inherent in the lowered VOC emissions is another advantage: solvent usage is reduced and substantial savings can be made, as shown in Figure 6-1.
Gallons of solvent required to apply one gallon of solids (100% efficiency)

Figure 6-1. Solvent Content of Paint Decreases as Paint Solids Increase

Figure 6-2. The Relation of Paint Sales to Changes in Volume Solids
Solvent savings can translate additionally into inventory reductions, plant space savings and reduced fire hazards. Figure 6-2 shows how increased volume solids decreases overall paint consumption.

Another advantage to having increased solids is the associated reduction in the number of spray application strokes to achieve a given film thickness. Theoretically, this can allow increased conveyor speeds.

The tendency of high solids overspray to remain gummy almost indefinitely causes cleanup problems. But this can also be an advantage because it allows the overspray to be reclaimed. A growing number of finishers are collecting overspray and either recycling it themselves or having a paint company do it for them. The overspray is collected on vertical baffles and flows down the baffles into a collection trough and finally into a container. All that is needed to reclaim it is to filter, check and adjust the color and restore the viscosity. Reclaiming the overspray has a bonus: that much less paint needs to be disposed of, further reducing operating costs.

**High Solids Disadvantages**

Although their advantages are pronounced, high solids do have various disadvantages. Low-molecular-weight resins needed in the formulation of these paints generally require high cure temperatures. Figure 6-3 compares the relative

![Figure 6-3. Cure Windows for High- and Low-Solids Coatings](image)
cure windows (time and temperature curing cycles) for high- and low-solids coatings. As a result, few single-component air-drying coatings are available. The air-dry or low-temperature-curing high solids coatings are restricted primarily to the two-part epoxies and the two-part urethanes. A 3-mil high-solids air-dry alkyd may be force-dried in 10 minutes at 200°F, but it may need 10 hours to air-dry hard at 77°F.

These low-molecular-weight resins are particularly sensitive to inadequate cleaning of substrates. Minor surface oil contamination can promote cratering, blistering, edge pulling and picture framing. Such flaws occur with all paints to a degree, but are more pronounced with high solids. Blisters and craters can result from oil or grease on the surface because these materials have low surface tension. When high solids coatings are applied over oil or grease, the paint solvents dissolve the oil or grease to some extent and absorb them into the film. This creates a region with low surface tension, causing the material to be pulled into the high-surface-tension paint. What is left forms the blister or crater in the finish.

![Figure 6-4. Viscosity Changes During Flash and Bake](image)

*Paint-film viscosity during the cure cycle.*
Cleaning must be more thorough with high than with low-solids coatings if these appearance defects are to be avoided.

The tendency for film thickness to build rapidly makes film-thickness control difficult. Extraordinarily fine atomization is required to overcome this hurdle, and not all spray guns are able to atomize high solids.

Overspray remaining wet becomes a disadvantage during booth cleanup. The tacky overspray can be time-consuming to remove. The sticky nature of the material makes it unpleasant to work around when it accumulates on surfaces, particularly those that people have to contact. Accumulations on walking surfaces are dangerous as well as messy. The overspray can be extremely difficult to detackify in waterwash booths. New “kill” agents that are able to reduce paint sludge stickiness have lessened this problem.

Because their viscosity tends to be somewhat higher than that of low-solids coatings, it may be necessary to include a paint heater in the system. Heaters are frequently needed with high solids to produce a low enough viscosity for proper application and good surface appearance.

HSSCs (high solids coatings) tend to decrease sharply in viscosity when heated, as shown in Figure 6-4. This can lead to the formation of sags in the paint film during oven cure. Rheology control agents can help prevent this from occurring, but if the coatings are sprayed too wet, oven sagging will still occur. A spray operator applying high solids coatings soon learns to deposit a “dry-looking” finish to prevent such sagging.

Another disadvantage with high solids is their narrow “time-temperature-cure window.” This means that oven times and temperatures need to be controlled closely.
Chapter 7

Waterborne Coatings

In solventborne coatings the only fluidizing media (a fluid able to dissolve the resin) is solvent. To be a waterborne coating, a paint needs to have water as the main fluidizing media. Most coatings qualifying as waterborne coatings also contain some solvent in the fluidizing media.

Strictly speaking, electrocoating (E-coat) formulations are waterborne paints because they contain a great deal of water. However, E-coat is deposited by electricity and is so unique that it will be considered in another chapter. Waterborne coatings (WBC) as a category are considered to be those coatings containing water that are applied by a conventional method such as spray.

Paint binders (resins) of the solventborne type are essentially “hydrophobic” (incompatible with water). Binders of the WBC variety have been rendered “hydrophilic”—they have been given a strong affinity for water. The conversion to hydrophilic is made by the resin manufacturer, giving WBC resins a distinctly different chemistry than traditional organic solventborne coatings. Almost any paint resin can be modified for use with WBCs. Some of the common WBC resins are acrylics, epoxies, vinyls, alkyds and polyurethanes.

Like their solventborne “sisters,” WBCs can be formulated for air drying or baking. As with solventbornes, air-dry WBCs tend to be somewhat low in gloss and low in water resistance, in comparison with bake WBCs.

WBCs are categorized into three types according to how the resin is fluidized (made liquid). These types are:

- Solutions
- Emulsions
- Dispersions

Solutions, emulsions and dispersions can be used in coatings whether WBCs or solventborne. As with solventborne coatings, the attributes of each of the three types of WBCs will vary somewhat with the resin used.

Alkyds and polyesters, for example, are more susceptible to hydrolysis (reaction with water) compared with acrylic resins. Most polyesters require a higher bake
temperature or a longer bake time than alkyds, although the polyesters may provide harder, tougher films and exhibit better weathering characteristics.

**Solutions**

A solution is a homogeneous dispersing of one or more substances into another substance. Examples of solutions are sugar dissolved in water and salt dissolved in water. As with a sugar-water or salt-water solution, each molecule of resin in a solution of paint is dissolved in the solvent, which is mostly water. Solution WBCs are called water-soluble coatings and water-reducible coatings. The term “water-reducible” is inappropriate, because this can apply to any WBC.

WBC solution resins contain chemically reactive groups that on addition of organic amine compounds form ionic groups to make them polar enough to dissolve in water. The solubilizing amine and water are volatilized in the cure process, reverting the water-soluble polar resins back to their insoluble nonpolar form.

If amines should volatilize from a water-soluble paint, the pH can drift down to a neutral value (pH of 7). The loss of solubilizer can make the resin insoluble (resin kickout). Poor flowout of solution WBCs can in some cases be traced back to low amine solubilizer levels.

WBC solution resins are low in molecular weight. Their small molecular size brings the advantages of hydrolytic and mechanical stability, minimal agitation requirements and long shelf life. The high amounts of amines present a modest health hazard in the form of potential respiratory problems and skin rashes. The resins have a high pH, reducing the tendency of solution WBCs to rust steel application equipment.

Other characteristics of WBC solution resins include:
- Excellent freeze/thaw stability
- Moderate storage limitations
- High gloss capability
- Excellent appearance
- High cost
- Application ease (in most cases)
- Minimal gun nozzle clogging
- Minimal water-solvent popping
- High cosolvent requirement (causing combustible flash points in some cases)

**Emulsions**

An emulsion in physical chemistry is a colloidal suspension of one liquid in another liquid. An emulsion consists of two immiscible liquids, one of which is
present as minute globules coated by a soap or other surface active substance and dispersed throughout the other liquid. The surface active coating is called an "emulsifier." It reduces interfacial tension between the immiscible liquids.

In an emulsion paint the emulsifier surrounds globules of resin molecules, which are dispersed in mostly water and some organic solvent. A well-known emulsion is mayonnaise, which consists mostly of a mixture of immiscible water and oil. The oil particles are coated with a thin emulsifying protein layer. The separate oil and water phases can be seen through a microscope, even after vigorous blending.

The manufacture and use of water-emulsion paint involves heterogeneous (having unlike qualities) systems whose behavior is more complex than that of conventional paints and solution WBCs. Some water-emulsions, for example, increase in viscosity when temperature rises, which is the opposite of what happens in a typical paint.

Waterborne emulsion paints are also called latex coatings. Contrary to what is frequently believed, latex paints contain no natural or synthetic rubber or rubber-like resins. The term latex is used by scientists to identify "any emulsion of an organic material in water." This is the most common type of paint purchased and used by homeowners for both interior and exterior application. Their value is not limited to "trade sales paints" (sold in retail stores). Latexes are used extensively for industrial maintenance applications as well.

The chemical nature of emulsion waterborne coatings allows them to be formulated at high volume solids without unduly high paint viscosities. The viscosity of emulsions is basically that of the continuous phase (in this case, water plus cosolvent) over a fairly wide range of paint solids concentrations, allowing the viscosity to be rather constant and not rise significantly at moderately high solids levels.

If solids levels are increased excessively, the material reaches a stage at which viscosity will increase sharply. It should be noted that the plateau in the viscosity-solids curve eliminates the possibility of a meaningful viscosity determination (as a normal aid in application) by the common viscosity cup method and a simultaneous approximation of the percent solids. The correlation between percent solids and viscosity is not linear with emulsion paints.

The chemical integrity of emulsions is threatened by freezing temperatures. Freezing can permanently separate the paint components, causing insolubilization of the resin—a phenomena called kickout.

Emulsions cure in the following sequence: The organic cosolvent evaporates, water evaporates and the resin particles coalesce (form a coating). In the case of an enamel, cross-linking of the resin occurs after coalescence.

WBC emulsion resins are high in molecular weight (100,000 to 3,000,000). The large molecular size brings the disadvantages of poor hydrolytic and mechanical stability. Over-sized pumps and low paint fluid pressures should be used due to the mechanical shear (mixing) sensitivity. The low amounts of amine in these resins
minimize the health hazard. They have a relatively fast air-dry rate, minimizing recoat times. Their relatively moderate pH tends to encourage flash rusting of steel.

Other properties of emulsion WBCs include:
- Poor freeze/thaw stability
- Rigid storage limitations
- Medium gloss capability (being improved)
- Medium appearance (being improved)
- Moderate in cost
- Ease of application (in most cases)
- High-solids application capability
- Low in odor
- Minimal VOC emissions

Because each of the water-soluble and water-emulsion types has distinct and separate advantages, attempts have been made to create coatings that are combinations of both. Some success has been achieved.

**Dispensons**

A liquid dispersion is a system of dispersed particles suspended in a liquid. A resin dispersion uses a blend of solvents with low polarities that force the resin molecules into a mild clumping.

A graph of viscosity versus solids for a dispersion paint also produces a viscosity curve that has a long plateau region into the high-solids range. The curve rises rapidly when the concentration gets so high that individual clusters of resin contact each other and begin tangling.

Dispersions differ from emulsions in that the resin clumps (clusters) are small and do not require added emulsifiers to form a stable fluid mixture. Vigorous physical mixture alone is employed to form a dispersion. Waterborne dispersions are also called “water dispersible,” which is imprecise because all waterborne resins are water-dispersible.

Waterborne dispersions are slightly different from emulsions but are close enough in properties to be considered as the same general paint type. The properties listed for emulsion WBCs apply practically universally to dispersion WBCs.

Slow-evaporating solvents remain in the applied coating film after the water evaporates, serving as “coalescing solvents.” Coalescing solvents supply needed fluidity to allow a film to form, as depicted in Figure 7-1.

**Solvent in Waterborne Coatings**

During the manufacture of waterborne coatings, organic solvents are added to
dissolve the resin. Because paint resins are essentially oil-like and do not mix with water, the chosen solvents are water-miscible, such as alcohols, ketones and esters. These “cosolvents” are somewhat polar and contribute dissolving properties to the resin. Suspension or solution of paint resins in water is frequently difficult without these organic cosolvents. The cosolvents also aid considerably in smoothing the flowout on the painted surface.

After the solvent and resin are mixed thoroughly, the mixture is made hydrophilic by the addition of amine or similar material. Then after the addition of pigments and additives, the mixture is reduced to the desired viscosity by the addition of water.

The organic cosolvent (at application viscosities) of most waterborne coatings is 2 to 30% of the fluidizing media; the remainder is water. Surprisingly, the organic solvent portion of these coatings can be quite high and they do not automatically meet EPA VOC emission limits.
Determining the VOC content of a waterborne coating isn’t necessarily as easy as simply knowing the amount of cosolvent added by the paint manufacturer. Amine solubilizers also can contribute to VOC emissions. To comply with VOC regulations, the volume percent of organic volatiles must be known. The easiest way to determine total VOC content is by gas-liquid chromatographic analysis, a method that is expensive unless an instrument of this kind is available. Other methods tend to be slow, cumbersome and inexact. Samples normally can be tested for VOC content by distillation of the volatile organic portions other than water. The volatiles usually will have a lower boiling point than water. Certain mixtures of solvent and water, however, make distillation and subsequent VOC determination impossible because the mixture becomes “azeotropic” (has a single boiling point).

The following case history illustrates how azeotropic solvent and water mixtures can distort VOC measurements based on distillation testing: A plant was cited for a VOC violation with a waterborne coating that had “excess of 1.37 pounds per gallon VOC over the maximum allowed of 3.00 pounds per gallon minus water.” The paint manufacturer claimed the paint had a total of only 2.66 pounds VOC per gallon minus water. When the regulatory agency was shown that adding water to the paint increased the apparent VOC content, the agency agreed that azeotropic distillation gave an erroneous VOC reading. The fine was promptly canceled.

Whenever WBCs are thinned to achieve the proper paint application viscosity, cosolvents should not be added. One obvious reason is that added solvent will raise the VOC emissions. Because of the viscosity relationship with added solvent, reduction with water must be done in tiny increments. Otherwise over-reduction is possible. A small amount of water addition can cause a sharp drop in the viscosity of the paint as shown in Figure 7-2.

To avoid complications from impurities and dissolved components in water, only clean deionized or distilled water should be used when making additions to WBCs, unless it can be shown that other water does not reduce film quality.

**WBC Advantages/Disadvantages**

The overriding reason for using WBCs is because their low VOC content usually allows compliance with EPA emission limits. This VOC advantage will surely lead to continued WBC growth in the future, especially as VOC limits are tightened.

**Pretreatment.** Pretreatment with WBCs is more critical than with solventborne paints. WBCs are not able to dissolve oil and grease that remain on surfaces after cleaning. WBC dirt and oil sensitivity tends to create blisters readily. Water has a high surface tension, creating potential edge-pull problems. The choice of cosolvent is crucial in reducing picture framing, craters, blisters, popping and edge pull.
Cost. Most WBCs cost more per gallon on an equivalent solids basis than organic solventborne materials. This reflects the higher cost to manufacture them. The cost on an equivalent square-foot-coverage basis for WBCs continues to be slightly higher than for organic solventborne paints, but the gap is narrowing.

Resin availability. Not as many resins are available for WBC formulation as with solventborne coatings. The inherent high viscosity of WBCs restricts their formulation to relatively low solids levels.

Modifications. Converting an existing low-solids solventborne coating line to WBC is simple, yet at the same time can be complex. Such an existing line may need to have piping, valves, etc., replaced with stainless steel or other nonrusting materials. This is particularly true when light-colored paints are used in which rust is readily visible. Depending on the local climate, air-conditioning may have to be installed to stabilize temperature and humidity for WBC application.

Process commonality. Conventional application processes can be used with WBCs, including all of the various spray methods, disk and turbine application, dip coating and flow coating. This gives WBCs an advantage over high-solids paints, where dip coating and flow coating are not possible.
Electrostatics. Because most WBCs are conductive, electrostatic application generally uses a system “isolated” from ground. Plastic stands and arms are used to isolate all conductive parts of the system from ground. Since the paint equipment components are “hot,” anyone touching a part of the system will drain off a large quantity of the electrical charge stored on the ungrounded system. An isolated system must be enclosed in a protective safety cage, and signs warning of shock hazards need to be posted. Electrically conductive objects can accumulate electrical charges if they are not grounded. The more massive the item, the more charge it can store. The degree of charging is expressed by “capacitance.”

“Grounded” systems have had marginal success. Few have had more than brief acceptance. “Remote” or “secondary” charging of the paint particles can be achieved by locating the charging electrode about 5 inches away from the gun tip. Secondary charging is generally not very effective, but in some cases a “charging ring” has been used with rotary WBC electrostatic application. The amount of electrical potential that can be reached with remote charging is only about 15,000 volts, far less than the 75,000 to 115,000 volts possible with normal charging devices.

A number of years ago systems purportedly would allow electrostatic spraying of WBCs with a fully grounded paint system by electrostatically charging the parts. This required that the parts be hung on insulated hooks. The hooks or hangers had a plastic section that prevented the part from losing its charge to ground. Parts were charged by contact with or proximity to a charging wire that ran along the length of the spray booth. Plants that had installed them said they were not effective. A similar process used remote “negative” charging of WBCs, plus “positive” charging of large vehicles on isolation stands. The corporation that installed it abandoned the method of application as ineffective.

Some plants have found that when WBCs are painted electrostatically, frequent “tripouts” of the electrostatic current limiter occur from “shorting” of the system to ground. This can be a vexing problem if locating the electrical short consumes a considerable amount of time.

Atomization. WBCs tend to be high in application viscosity and surface tension (be highly cohesive). As a result the paint does not atomize as readily as solventborne paint. This means having to settle for a low finish quality or for low transfer efficiency. To get good breakup in air spray, high air pressures are used when applying WBCs. This can reduce paint transfer efficiencies below 25%.

Application problems. The major disadvantages with WBCs tend to be the difficulty of application without sagging and the problem of avoiding solvent popping and boiling when parts are in the oven. This can be a narrow tightrope to walk. To understand why this is so, it is well to review what happens when solventborne paint is sprayed.

When solventborne paint is sprayed, the solids content (and viscosity) of the paint increase substantially after exiting the gun tip. This is the result of
evaporation of solvents from the very large surface area of the fine atomized droplets moving toward their target. In the short time before the droplets hit the workpiece, the solids can increase 20 to 25%. This helps prevent sags on freshly coated parts. Solventborne coatings use a blend of four to eight solvents with varying evaporation rates to avoid a sudden excess of solvent evaporation. With WBCs, however, much of the volatile portion of the sprayed droplets is water. Water has a high boiling point, so virtually none of it evaporates while the WBC droplets travel from the end of the gun to the workpiece. Thus the “as-sprayed” solids percent is identical to that of the paint on the freshly coated part. Because so little fluidizing media evaporates from the paint droplets between the application device and the workpiece, it is often difficult for the operator to achieve a sufficient film build while at the same time avoiding running or sagging of the material. The applicator must walk a narrow path between inadequate film build and paint runs.

Paint heaters set at 90 to 105°F may help reduce or prevent such sagging. Some WBCs have reverse solubilities, so increased paint temperature can complicate the situation by raising the viscosity of these coatings.

High humidity in the spray application area can add to the problem by reducing flashoff to near zero. The application area may need to be air-conditioned to control the humidity. The high cost of air-conditioning may prohibit the use of WBCs. Slow air-dry times will be experienced when humidities are high. WBCs may be unusable under such conditions. WBCs need to be sprayed at somewhat higher viscosities to avoid runs and sags. especially when it is necessary to achieve more than 1 to 1.5 mils dry-film thickness.

The slow flashoff of water in humid weather can make popping and boiling in the oven a frequent problem, particularly if an appreciable film build is necessary. Heated flash zones are frequently necessary to remove enough of the water so that popping and boiling defects are not experienced in the oven. Zoning of bake ovens may also be necessary to prevent water boiling and popping.

Water’s high “heat of vaporization” can cause problems in curing WBCs in a bake oven. Little of the water evaporates until the temperature of the applied coating reaches 212°F, then all of the water will tend to evaporate at the same time. The “outrush” of water vapor can tend to cause blister and solvent-popping problems.

Agitation. Some WBCs are sensitive to being stirred or pumped. This is particularly important since WBCs as a whole tend to settle rapidly. Excessive agitation can have a “butter churn” effect and “break” emulsions. Certain filters can produce the same problem. The kicked-out resin then forms an insoluble mass, clogging filters and spray guns. Sometimes the resin globules are soft enough to be pushed through filters. Then they can reach the gun and be ejected as small gelatinous globs onto the workpiece. These must be sanded off after curing, and the part must be resprayed.
**Odor.** One of the great advantages of WBCs is their low odor. Easy cleanup is another advantage. However, since the resins are designed to be compatible with water, it is sometimes difficult to get WBC overspray to float or sink in waterwash booth reservoirs. As a consequence, some WBCs are difficult to detackify. Continual improvements are being made in “kill” agents, however.

**Fire Hazard.** Another advantage of WBCs is reduced fire hazards (low flash point or no flash point). This can be a significant plus in many plants. Some WBCs will not ignite even when an open paint pail is subjected to the direct application of a blow torch. After all volatiles evaporate, however, the cured WBC is just as flammable as a cured organic solventborne coating. If the organic solvent content of a WBC is high, however, these paints can still burn.

**Storage.** WBCs should be stored inside to prevent freezing. Expansion on freezing can burst paint containers, and ice formation during freezing can damage the paint, especially by kicking out emulsified resins.

**Dip tanks.** In a WBC dip operation tank size is critical. The tank should be small enough to get fast paint volume turnover. This will help avoid instability problems inherent with WBCs. Complete turnover of the tank volume in one or two months would be considered ideal. With WBC dip coat and flow coat, drain-off continues from the parts for a considerable distance. To recover some of this paint, the drip zone can be rinsed back with a fine water mist or a small amount of cosolvent. One of the most successful recovery methods is to use the paint itself to flush back the coating from the drip zones. This results in a clean and economical operation. Water and cosolvent loss are somewhat reduced when dip tanks are covered during nonuse. This practice is more often used with organic solvent dip systems. Nevertheless, covering the tank is a wise practice because it helps to keep foreign materials out of the paint.

**Foam.** Foam sometimes can be a problem in flow coat and dip coat WBC systems. The emulsifiers and other coating components act as detergents in the system. When the paint material is agitated, it foams like most detergent/water mixtures. The paint foam gets on parts, dries and creates appearance defects. Foam can stall pumps and distort the readings of monitoring devices.

**Summary**

In summing up WBCs, they have many advantages and probably as many disadvantages. One thing is certain, WBC application requires tight process control. Some plants have been lured by WBC advantages to switch over to them, but after a while have been swayed by their disadvantages to change to another coating system. Other plants have changed to WBCs and continue to use them.
Chapter 8

How Paint Is Applied—Part 1

Although no known records exist about early paint application, the most probable method of application was by some form of spreading. The methods used by cavemen in painting their caves almost certainly included the use of their fingers, sticks and perhaps straw-like spreading devices. The application of paint by means of a device held in the hand evolved over the years and even now is one of the most common methods of applying paint, either for art or industry, by means of a brush.

The essential feature of paint brush construction is primitive—merely tying or binding straw-like fibers together. The quality differentiation of brushes is linked to two parameters: the nature of the bristles and how they are bound.

The nature of spreading paint by brushing demonstrates several obvious points:

- It is slow
- It is labor-intensive
- It is paint viscosity-dependent
- It is messy
- It may be hazardous

That painting with a brush is slow, labor-intensive and messy is apparent to anyone who has ever tried it. If the paint is too thick, it won’t spread easily; if it is too thin, it will spread easily but the application will be extremely messy. It may be hazardous in the sense that the paint fumes generally envelop the painter and, in the past, many paints contained toxic substances such as lead.

**Modern Application Methods**

A number of application techniques have been developed in more recent times to improve the efficiency of paint application and the appearance of the cured coating.
Rolling

Painting with a roller is faster than painting with a brush, but it, too, has drawbacks. A roller cannot get into hard-to-reach areas and the application often requires touchup with a brush. In addition, rollers generally absorb—or “load up”—a substantial amount of paint, most of which cannot be saved when the job is done.

Dipping

Painting by dipping, as shown in Figure 8-1, is much faster than brushing or rolling and much less labor-intensive. Dipping, however, is extremely dependent on the viscosity of the paint, very messy and is high in hazard. The viscosity of the paint in a dip tank must remain practically constant if the deposited film quality is to remain high.

The film thickness in dipping can be controlled by varying the viscosity and by the rate that parts are withdrawn from the dip tank. Thin paint films are produced by a slow withdrawal; an increased film thickness results from an abrupt withdrawal.

Dipping is not suitable for many hollow-shaped items. They tend to float as they contact the paint and often become disengaged from their hangers or hooks.

Color change is very slow and generally not feasible for most dip operations, although sometimes multiple tanks mounted on rollers are used. As needed, the various color tanks are rolled into position under the conveyor line. This technique is not done in many plants.

A flammable paint can constitute a major fire hazard and sometimes safety dump tanks may be required by local fire codes. For all such tanks, an efficient fire-extinguishing system must be installed as a safety measure. Paint drippage from parts exiting the dip tank creates a mess that adds to the fire hazard.

![Figure 8-1. Schematic Sideview of Painting by Dipping](image-url)
Flow Coating

In a flow coat system, as shown in Figures 8-2 and 8-3, 10 to 80 separate streams of paint are directed to impinge on the parts. The streams may flow out of holes drilled in pipes or through short, crimped pipe outlets. The paint headers are arranged so that all surfaces of parts carried through the flow coater on the conveyor are painted. Paint is liberally applied to all surfaces of the parts. The paint flowing off the parts drains into a sump, from where it is pumped through filters and recirculated to the flow coat paint reservoir.

Paint film thickness in flow coating is controlled by adjusting viscosity. Flow coating also needs a drippage zone, which adds to cleanup maintenance.

Both dipping and flow coating tend to be used to coat items whose appearance is not vitally important and to apply primers. Topcoats are not commonly applied by dipping or flow coating. Coatings applied by these methods have only poor to fair appearance unless parts are rotated during the drippage period.

Figure 8-2. The Coating Chamber in Flow Coating
Both dipping and flow coating have the disadvantage that the principal control of dry-film thickness is the viscosity of the paint. Automatic viscosity controllers that add solvent as required are frequently used to maintain tight control of paint viscosity. The amount of paint that drains from the parts depends on the viscosity. If viscosity is allowed to go too low, insufficient paint build will result. This could cause a large number of parts to need repainting. On the other hand, if the paint viscosity should rise too high, then extra paint will be applied. This can increase paint costs and can also plug small holes in the part.

When items are dipped or flow coated, the drain-off pattern may contribute runs or heavy lines on the parts. This can occur around through-holes that are large enough to avoid being filled with paint. Sometimes extra paint builds up as “fatty edges” along the bottoms of parts. If excessive, dried paint “tears” can form that resemble icicles.

A significant disadvantage of these two systems is that the appearance of the finish is not as attractive as those produced by more sophisticated methods. Despite the limited flexibility, the advantages make them highly desirable methods for painting certain kinds of parts.

Both methods achieve very high paint transfer efficiencies, often 90% and higher. The techniques are well suited for automation with conveyorized paint lines. Manual flow coating is nonexistent and hand dipping of parts is rare. The latter is suitable only when a very limited number of parts is to be painted.
How Paint Is Applied — Part 1

Painting by dipping or flow coating is fast and easy, involves a relatively low installation cost, requires little maintenance and has a low labor requirement. In addition to a paint attendant, the only other labor requirement is that workers hang parts to be painted onto the conveyor line and remove them after they have been cured. Thus in addition to the low labor requirement, the skill required is also low.

**Continuous Coaters**

A variation of the flow coat process is the “continuous coater,” as shown in Figure 8-4. An enclosed tunnel-like painting machine captures and reuses the excess paint that runs off coated parts. It employ directed sprays rather than streams of paint.

Tennis racquets, metal panels and engines have been coated by this technique. Reuse of the paint within a confined space contributes to high paint transfer efficiency and reduced VOC emissions because of the solvent vapor capture capability of continuous coaters.

One drawback to the method is that all parts being coated must be roughly the same size and shape. The gun-to-part distance should be kept uniform for best part appearance.

Figure 8-4. Schematic of Nordson Continuous Coater
Dip-Spin Coaters

Dip-spin (centrifugal) coaters are designed to paint large-quantity batch loads of small parts, such as hairpins, clips and fasteners. A wire basket containing up to 50 lb of parts is immersed in a reservoir of paint. The basket is raised, the parts are allowed to drain, the basket is spun to remove excess paint, the parts are dumped onto a mesh conveyor belt and moved through a bake oven. The entire process is automatic.

The main advantage is the extremely high productivity. A disadvantage is that some of the painted parts dumped on the conveyor may stick together in the oven, leaving paint voids when they are separated. These parts may be run through the process a second time to eliminate the defects.

Curtain Coating

In curtain coating, paint flows at a controlled rate from a reservoir through a wide variable slot onto flat work being conveyed horizontally through the waterfall-like flow of paint, as shown in Figures 8-5 and 8-6. Curtain coating is suitable only for items that are flat or at least relatively so. The fixed width of the coating pattern is about 18 to 48 in., depending on the size of the machine in use.

Figure 8-5. Curtain Coating Line
The volume of paint released and the speed of the conveyed flat work determine the thickness of the applied coating.

Because the paint that drops between the parts from the continuously falling curtain of paint is captured and recirculated, virtually no coating material is wasted. Extremely uniform coating thicknesses are possible, however, only one side of a flat item can be painted at a time.

Curtain coating also is highly viscosity-dependent. Because it is simpler and uses less complex equipment, curtain coating may be preferred for lower production runs over roll coating.

**Roll Coating**

Roll coating is also limited to flat work. Paint is applied by one or more auxiliary rolls onto an application roll, which rolls across the conveyed flat work. The application roll can either turn in the same direction as the conveyed work (direct roll coating), as shown in Figure 8-7, or turn in the opposite direction (reverse roll coating), as shown in Figure 8-8. It too is extremely viscosity-dependent. It also is a clean process that carries a great deal of fire hazard due to
the large surface area of the paint-covered rollers, which contributes to heavy solvent evaporation.

"Precision roll coating" is a version of direct roll coating that employs engraving on the "doctor" roll running tightly against the "coating" roll. By engraving the doctor roll, it is possible to regulate accurately the thickness of paint that will be transferred to the coating roll and then to the surface being painted. A scraper blade on the coating roll removes excess paint so that the coating roll always

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**Figure 8-7. Schematic of Direct Roll Coater**
(The Black Bros. Co.)

**Figure 8-8. Schematic of Reverse Roll Coater**
(The Black Bros. Co.)
How Paint Is Applied — Part 1

applies only the exact amount of coating released to it by the doctor roll. Reverse roll coating can be used to apply fillers to wood substrates to smooth the surface, eliminating open pores and low spots.

**Coil Coating**

The roll coater is employed as the means of paint application in coil coating. The term “coil coating” refers to the painting of flat metal (steel or aluminum) sheet up to 72 in. in width. A coil coating line, as shown in Figure 8-9, automatically unwinds a roll of metal, cleans it, applies a conversion coating, paints it, bakes it and rewinds the painted metal into another coil. Some coil coating lines operate at speeds in excess of 600 fpm. The painted metal is sent to a fabricating plant for shearing, forming and assembly into various products. The main advantage in fabricating from prepainted metal is that no paint line is required for the completed parts.

![Figure 8-9. Drawing of Coil Coating Line](image)

The problems associated with VOC emissions have made it attractive for some manufacturers to stop painting in their own plants and to manufacture their products with parts fabricated from prepainted metal. Because the metal is cleaned, conversion coated and painted while flat, parts made from this material are therefore finished uniformly.

When fabricating parts from precoated coil, precautions must be taken to hide the uncoated cut edges. This must be done to avoid visible corrosion that can readily form on unprotected metal. Edges can often be hidden by folded seams, but if they cannot be hidden, they need to be painted. Should painting of exposed edges be required, much of the advantage in using prepainted metal is lost.

Prepainted metal is used on autos, appliances, cans and related containers, architectural panels and on numerous other products. The large volume output
that is possible per line is an important factor in the economics of the coil coating industry. Coil coating was developed in about 1930 to paint steel in a thin, narrow, continuous strip for venetian blind manufacturing. In 1988 about 200 coil coating lines were operating in North America.

Because coil coating lines may be over 1000 ft in length, "threading" a strip of metal through a coil coating line is a fairly time-consuming process. If every coil had to be "threaded," the process would be very inefficient. To avoid this, a scrap coil is always the first and last coil in a run. As the line is started, the leading edge of the new coil is fastened to the trailing edge of the scrap coil. When the scrap coil is wound, its trailing edge is sheared, and the leading edge of the production coil is threaded into a new take-up roll.

An "accumulator" at the line entry and exit allows new coils to be started, and painted coils to be moved out without stopping the lines. The entry accumulator stores some 300 ft of strip to feed the line while a new coil is being loaded and fastened to the end of the in-process coil. The exit accumulator runs empty until time to change coils at the painted end. That accumulator then collects the painted stock until the painted coil is moved out and a new take-up roll is started.

The process begins with a spray application of hot alkaline cleaner to both sides of the strip to remove oil and grease. Next is a rinse with warm water, followed by abrasive brushing (cleaning) on both sides of the strip (if needed). Then alkaline cleaning is repeated. A final immersion rinse in hot water dissolves any alkaline residues and completes the cleaning operations.

The strip is then ready for dip, spray or roll-on of the chemical conversion solutions. The conversion coat improves the adhesion of the paint to the metal. The type of pretreatment that is applied depends largely on the metal substrate and the kinds of parts to be manufactured from the prepainted stock. For cold-rolled steel, conversion coatings are microcrystalline iron phosphate or zinc phosphate. Iron phosphate is thinner and more flexible, but zinc phosphate offers superior corrosion protection.

Two conversion coatings used on hot-dipped or electrogalvanized steel are zinc phosphate and chromate-sealed oxide. The oxide coating is formed in three steps. First the zinc surface is treated in an alkaline solution, resulting in formation of the layer of oxide. A cold-water rinse follows. Unless this rinse is thorough, blisters and paint peeling can result. Any salts left from the first step can react with the metal under high humidity conditions. The last step is a dilute chromic acid rinse that yields a complex oxide to promote paint adhesion and flexibility. It does not have as good corrosion resistance as zinc phosphate. Hot-dipped aluminum-zinc coated steel requires a chromate conversion treatment for the best corrosion protection. Chromates can be used as well on galvanized steels. "React-in-place" and "nonrinsed" conversion coating processes avoid the costs and problems associated with waste water treatment for removal of environmentally objectionable substances. Pretreatments that eliminate rinsing have not equalled
the anticorrosion properties of the phosphate or chromate coatings.

The metal strip then passes through an air knife drier (high-intensity air blowoff) before entering the coating section. A roll coater applies paint by forward or reverse coating to one or both sides of the strip, depending on the specific product requirements. Figure 8-10 shows a coil coating line roll coater applying a single color; Figure 8-11 shows a coil coating line multihead roll coater system capable of applying several colors. Epoxies, vinyl plastisols, fluorocarbons, polyesters and silicone-modified polyesters are often used. From the coating rolls the strip goes to the bake oven to drive out solvents and to cross-link (cure) the paint. To shorten oven dwell time and reduce the length of the oven, a very high temperature (about 750°F) is maintained. A 15-minute bake for strip traveling at 10 to 12 feet per second would require an oven roughly two-thirds of a mile long. For this reason bake times are normally held to about 5 minutes. This still will normally require an oven over 1000 feet in length. After baking, the strip is air-cooled and water-quenched. Should a second coat be necessary, the coating and curing are repeated.

The coating is inspected visually (and sometimes instrumentally) as the painted strip winds onto the takeup roll. The finished coil is taken off the machine and moved from the area for shipment, storage, embossing or slitting. Samples are cut
from the completed coil at periodic intervals for quality control tests. If required, samples are sent to customers for preshipment approval.

The coil can be slit to any width, cut into flat sheets of various size or transported in coil form as desired. Lines may also be equipped to print patterns such as wood graining. Thick-film coatings can be embossed into various textures. Many coil lines are able to laminate decorative or functional films onto the metal as well. Acrylic film can be laminated onto galvanized steel or onto aluminum for building applications; solid-color and decoratively printed vinyls are being used on appliances, cabinets, lighting fixtures and many related items. Even cork, paper and rubber are being laminated onto specialty goods.

Two problems for the coil coating industry are fastening methods for parts made from prepainted coil and protecting the bare metal edges where the strip is cut. Many potential users of prepainted stock depend on welding for joining parts. Although some paints (weldable zinc-rich primers, for example) do not interfere with welding, most paints prevent effective welding. Joining methods that have been employed for coil-coated parts are adhesives, self-tapping screws, rivets and spring clips. Bare edges can sometimes be located in nonvisible areas with proper product design. Hem folds, lock seams, plastic caps or plugs and plastic beading are common ways to hide cut edges from view.
Chapter 9

How Paint Is Applied—Part 2

Electrocoating and Autodeposition

Both electrocoating and autodeposition involve immersing the part to be painted into a waterborne solution containing the “paint.” Immersion of the part is the only thing these techniques have in common, however. Electrocoating involves the use of electricity; autodeposition does not.

Electrocoating

Electrocoating—also called electrodeposition, electrophoretic coating, electropainting, the electrodeposition of polymers (Elpo) or, most commonly, E-coat—is the electrical deposition of a paint film from a waterborne organic solution onto a part—a process in which the part is one of two electrodes forming an electrical cell. A source of electricity, the two electrodes and the solution comprise the electrical cell. The part to be painted, the other electrode and the solution must be electrically conductive to complete the cell requirements.

E-coat application is very similar to the electroplating of metals; a process which also involves a source of electricity, two electrodes and an electrolyte (instead of an organic solution) but which deposits metal instead of paint. Unlike the electrodeposition of metal in electroplating, the electrodeposited E-coat paint must be baked and cured.

The E-coat process is extremely efficient, depositing a mostly uniform coating on all surfaces that can be reached by electricity. This includes all surfaces except those in confining Faraday cage areas, such as inside a long, narrow-diameter pipe.
In such a configuration the electrodeposition occurs at the high-current-density areas; e.g., conductive surfaces closest to the source of electricity.

Parts to be painted are usually conveyed in and out of an E-coat bath with an overhead conveyor, as shown in Figure 9-1. Sometimes, however, parts are lowered into an E-coat bath “elevator style,” as shown in Figure 9-2. Some systems raise the entire E-coat tank to the parts, as shown in Figure 9-3, a process which allows changing colors by switching tanks. The basic components of an E-coat system are shown in Figure 9-4.
Figure 9-3. E-Coat Tank Hydraulically Raised to Parts

Figure 9-4. Basic Components of an E-Coat System
E-coat power supply requirements vary according to the total area of parts to be immersed in the solution at any given moment. The power supply must be able to provide a current density of from 1 to 4 amperes (amps) per square foot of surface of the part being coated. This current density will produce a normal film build of approximately 1 mil in thickness. A typical high-capacity power supply can provide 50 to 900 amps of direct current at 75 to 500 volts.

The part being coated and the conveyor carrying the part are always electrically grounded, which greatly simplifies safety and eliminates the need to insulate the conveyor. The other electrode, however, is charged, creating an electrical potential in the solution that results in the deposition of the paint film.

In a “cathodic,” or “cationic,” E-coat system the part being coated is the grounded cathode, and the other terminal, the anode, is charged positively. In an “anodic” system the part being coated is the grounded anode, and the cathode is charged negatively. The anodic E-coat was developed first and made commercial before cathodic. The essential shortcoming of anodic E-coat relates to the nature of a fundamental electroplating cell. In such a cell the anode dissolves, and the dissolved ions enter the deposition solution, where they drift over to and deposit on the cathode. Thus in anodic E-coat the part (anode) is simultaneously dissolving to a small degree while it is being coated. The dissolved ions of the anode tend to discolor light-colored E-coats and lower corrosion resistance.

When cathodic E-coat became commercial, the basic defect of anodic E-coat was eliminated. The cathode—the part being coated—does not tend to dissolve. In addition to eliminating discoloration, cathodic E-coat also improves corrosion resistance; the absence of deposited substrate metal improves the integrity of the paint film.

Most of the discussions in this chapter will relate to cathodic rather than anodic E-coat. Anodic systems are still in use, and some new anodic systems are being installed, but the trend is toward cathodic E-coat because of the superior films. A disadvantage is that cathodic deposition solutions are more costly than anodic types. Some pigment colors are more stable in the alkaline anodic baths than in the acidic cathodic baths.

E-Coat Solution Constituents

An E-coat solution, or bath is similar in content to conventional waterborne paint, but the resin molecules are chemically modified to enhance their water solubility. For this reason E-coat paint cannot be used in ordinary dipping; it must be electrically deposited or film appearance and durability suffer dramatically.

Like conventional paint, an E-coat bath contains resin, pigments (unless a
clearcoat), solvent (water and a cosolvent) and additives. It is the chemical structure of the resin that makes an E-coat bath different from other paints. Most of the solvent in an E-coat bath is water. The water content puts E-coat in the family of waterborne coatings. A typical E-coat bath will contain from 2 to 6% of a high-boiling water-soluble solvent, such as butyl cellosolve or hexyl cellosolve (ethyleneglycol monobutyl ether or ethyleneglycol monohexyl ether). Moderately higher cosolvent levels do not affect the coating process, but if excess cosolvent is added, VOC emissions may become unacceptably high.

Not just any waterborne coating can be used as an E-coat bath; the resins must first be modified to contain certain chemical groups. The resins are treated with appropriate solubilizer chemicals and form positively charged (cathodic) or negatively charged (anodic) molecules called polymer ions. In their ionic form these resins are very polar and are soluble in water because water is also highly polar. They are, however, not interchangeable.

For anodic resins, carboxylic groups are chemically attached to resin molecules. The resin is mixed with potassium hydroxide, sodium hydroxide, triethyl amine or other amine compounds to solubilize the resin molecules.

Cathodic E-coat resin molecules are chemically modified so that tertiary amine groups are located along the backbone carbon chains of the molecules. Without ionizable groups such as amines, the resin cannot be used in an E-coat formulation. The tertiary amine groups, when treated with dilute acid solubilizers, such as acetic acid or formic acid, will form the necessary positively charged ions needed for cathodic E-coat.

In theory any type of resin can be modified for use with E-coat. The most commonly used resins, however are epoxies and acrylics. Epoxy E-coat paint films, like any other epoxy, tend to chalk when exposed to ultraviolet (UV) light. This is generally not a problem if the epoxy E-coat film is to be a primer. If the epoxy is to function as a topcoat, then it shouldn’t be exposed to UV light unless chalking does not present a problem.

E-coat paint films that require high appearance standards employ acrylic resins. These are resistant to attack by UV light and have outstanding weatherability.

In formulating E-coat resins, chemists select cross-linking agents, such as aromatic and aliphatic isocyanates, that are appropriate to the end use of the paint film. The aromatic cross-linkers, however, tend to cause yellowing in the paint film upon outdoor exposure; aliphatic cross-linkers do not. To avoid darkening, acrylic resins are cured with the aliphatic cross-linkers.

Since isocyanates react with water, and E-coat baths contain water, chemists “block” the isocyanates to prevent water reaction. The blocking is done chemically by “tying up” the water-sensitive ends of the isocyanate molecule with a blocking agent. The blocked isocyanates deposit into the E-coat film but the blocking agent is driven off by the high E-coat bake oven temperatures, thereby allowing the isocyanate group to cross-link with the E-coat resin molecules.
**Bath Chemical Reaction**

In both anodic and cathodic E-coat systems the bath chemical reactions are essentially similar except for different chemical groups and the opposite electrical charge on the polymer ions. For the initial fill of the E-coat tank, insoluble neutral resin is premixed with a solubilizer (most often acetic acid) to produce soluble positive resin ions. Formed simultaneously are negative solubilizer (acetate) ions according to the reaction:

\[
\text{neutral resin} + \text{acetic acid} \rightarrow \text{polymer ions} + \text{acetate ions} \\
(\text{positive}) \quad (\text{negative})
\]

When the part to be painted is immersed in the bath, direct current is passed through the solution. The passage of current causes an electrochemical reaction that converts the water-soluble polar ionic resin polymer ion into a neutral nonpolar molecule that is not water-soluble. The neutral molecules become insoluble and can no longer stay dissolved in the bath. As a result, resin molecules are deposited directly onto the surface of the parts to be painted.

Such large amounts of direct electrical current pass through the bath that some of the water decomposes into oxygen gas, hydrogen gas and, more importantly, hydrogen ions (H\(^+\)) and hydroxide ions (OH\(^-\)). At the cathode hydrogen gas and hydroxide ions are formed. Simultaneously oxygen gas and hydrogen ions are produced at the anode. Normal plant air circulation sweeps away the flammable hydrogen gas to prevent the possibility of an explosion or fire. The amount of hydrogen generated is generally of low volume.

The positively charged (cationic) soluble resin ions interact with the negatively charged hydroxide ions generated at the cathode (the part being painted). Combination of the two oppositely charged species forms water and neutral insoluble paint molecules. In this way items can quickly be coated. As direct current continues to pass through the E-coat, increasing amounts of resin become insolublized. Figure 9-5 depicts what happens at the electrodes in a cathodic E-coat system.

As additional neutral paint molecules deposit on the metal surface, the part becomes increasingly electrically insulated. This gradually reduces the current flow, slowing the rate at which the paint film is deposited, and finally stops it almost completely. In most cases about 0.5 to 1.8 mils are deposited in 2 to 4 minutes. After about 4 minutes, virtually no additional coating is deposited. It is not possible to produce E-coat films over 2.0 mils thick.

Only one coat of paint can be applied by E-coat. If an object has a layer of any type of paint film, the surface will be too limited in conductivity for coating to deposit.

The current flow, typically 1 to 4 amps/square foot, is regulated by the voltage setting; greater voltages are used to obtain higher film thicknesses. If the voltage is
Positive resin ions attracted to the CATHODE are neutralized to form an insoluble resin layer.
Negative solubilizer ions attracted to the ANODE are neutralized to form solubilizer molecules.

Figure 9-5. Cathodic E-Coat Electrode Reactions

set too high, however, excess current will flow between electrodes and gases formed by electrolysis of water can be generated under the newly formed paint film causing the paint to lift off in spots as large as an inch in diameter. The voltage at which this occurs is called the "rupture" voltage. Rupture tends to occur on projections or other areas of parts that are closest to the electrodes because current density will be greater in those areas.

At the other electrode, the anode, a similar process occurs with the acetate ions from the solubilizer. Oxygen gas and hydrogen ions are generated at the anode, and the attraction of opposite charges causes negative solubilizer ions to be drawn to the positive anode. Positively charged hydrogen ions are generated by electrolysis of water in the vicinity of the anode. The negative solubilizer ions (acetate ions) combine with positive hydrogen ions to regenerate neutral (in the sense of electrical charge) acetic acid (solubilizer) molecules. The reaction is:

$$\text{CH}_3\text{COO}^- + \text{H}^+ \rightarrow \text{CH}_3\text{COOH}$$ (acetic acid)
Resin, solubilizer and pigment are periodically added to the bath, but the coated parts remove only resin and pigment. If nothing were done, the solubilizer concentration would continually rise. Three methods can be used to prevent excess solubilizer from accumulating in the bath. Any one or all of the following methods may be used in a given system to keep solubilizer levels below an appropriate limit:

- Anode semipermeable membrane
- Solubilizer-deficient makeup resin
- Ultrafiltration/reverse osmosis

**Anode semipermeable membrane.** If the anode is encased in a semipermeable membrane, small molecules and ions (including acetate ions) will go through the membrane. Small negative ions pass the membrane pores rapidly because they are attracted to the positive anode. The paint resin ions and the pigment particles will be excluded because they are too large to pass through the membrane pores. When acetate solubilizer ions (CH$_3$COO$^-$) are neutralized by combining with H$^+$ ions, they become concentrated to a large extent within the anode enclosure. An aqueous flush called the “anolyte solution” is introduced into the bottom of the anode compartment. The anolyte is essentially water that slowly flushes excess acetic acid out of the cell directly to drain or to a holding tank for recirculating the anolyte.

As this flush water recirculates, its acetic acid content slowly increases. Normally the pH of the anolyte flush ranges from 2.5 to 5.0 and the electrical conductivity from about 250 to 950 micromhos. Periodically some of the dilute acetic acid solution in the tank must be released to drain. (Acetic acid is so mild in dilute form that it is used in a large number of foods. Vinegar, for example, is a 5% solution of acetic acid.) Deionized water is added to replace the anolyte solution released to drain. Upon neutralization with caustic soda in the waste treatment holding tanks, the dilute acetic acid forms sodium acetate, a nontoxic substance that in dilute solution can be drained directly to the sewer.

**Solubilizer-deficient makeup resin.** Another way to reduce the solubilizer content is by using “solubilizer-deficient makeup resin.” If replenishment resin is added that is not fully neutralized with solubilizer, it is possible to force the excess solubilizer in the bath to become the source of the needed solubilizing acetic acid. If added slowly and with very thorough mixing, solubilizer-deficient makeup resin will be blended into a large quantity of the tank contents. There it reacts with the solubilizer in the bath to form fully solubilized resin.

**Ultrafiltration/reverse osmosis.** Ultrafiltration and reverse osmosis are terms that describe forcing molecules of a liquid through a filter membrane. Both techniques are essentially the same, differing only in the pressures and membranes used. Reverse osmosis uses the higher pressure. Ultrafiltration is used to separate resin and pigment from water (and solubilizer) for rinsing parts. A few systems use reverse osmosis to further purify the ultrafiltration-generated rinse water by removing solubilizer and ionic contaminants.
Rinsing

A part emerging from an E-coat bath has a deposited paint film that is covered by a wet solution consisting of bath solids (dragout). An elaborate rinse system removes the dragout before the coated parts are baked. Extremely large quantities of rinse are required to remove all dragout materials that may cling to the part. If dragout were not thoroughly rinsed away, the E-coat film quality would suffer.

Poor rinsing causes pronounced E-coat roughness that can require sanding of the film after curing. Sanding E-coat films is possible, but it is not easy to do because they are extremely hard. The slow, tedious sanding increases labor costs. Thorough E-coat rinsing is, therefore, absolutely essential.

The need for such thorough rinsing, however, causes a major dilemma. The rinse water volume must be large, and the amount of rinsed dragout is very low. Discharging all of the rinsed-off bath solids to drain can be cost-prohibitive and would cause an excessively high “biological oxygen demand” for the sewer system. The problem is complicated because the small amount of solids and the large quantity of rinse water cannot economically be separated. Filtration, distillation and related methods are much too costly for taking bath solids out of the rinse. If this problem could not be resolved, nearly all E-coat processes would be stymied because most plants could not afford to discard the important volume of solids along with the rinse water. Continually adding fresh deionized water to rinses to remove the dragout and discarding all ultrafiltration solution is cost-prohibitive.

A possible answer might be to allow the rinse water and the small amount of dragout to run directly back into the E-coat tank. But if continuous fresh water were used for rinsing, the E-coat tank would rapidly be diluted and accumulate such a large amount of extra water that the tank would quickly overflow.

The remedy to the problem is found by using ultrafiltration to withdraw (temporarily) a small portion of water-like “permeate” from the E-coat bath. The permeate is “squeezed” out of the E-coat bath by ultrafiltration. This “borrowed” permeate is then counterflowed through the rinse system. All of the rinse permeate is collected and reused in several (usually three) separate counterflowing rinse stages. The used rinse permeate is returned to the bath from an initial rinse located directly over the exit end of the E-coat tank. Figure 9-6 shows how ultrafiltration is tied into an E-coat rinse system.

Thus the ultrafilter system temporarily appropriates a small portion of the water in the bath, uses it to rinse off the parts and finally allows the permeate plus the rinsed-off dragout to flow back into the E-coat tank. This closed-loop filtration system continually provides enough permeate for rinsing without diluting the bath. The permeate that is extracted from the bath by ultrafiltration is also referred to as “ultrafiltrate” and “flux.”

Factors that can affect the amount of permeate that is produced for E-coat rinsing include: 1) the concentration of paint resin and pigment, 2) the pressure of
Figure 9-6. Closed Loop Ultrafiltration

the bath flowing through the ultrafilters, 3) the flow rates of bath through the ultrafilters, 4) the bath temperature, 5) the pH, 6) the cosolvent concentration, 7) the pigment-to-binder ratio of the bath solids and 8) the presence of foulants such as chromates or phosphates from pretreatment carryover and dissolved solids from the use of tap water rather than deionized water.

Under optimum conditions the permeate production rate is about 1.0% of the total bath flow through the ultrafilters. Figure 9-7 shows a bank of ultrafilter cartridges in a fairly large E-coat installation. As the filters gradually become fouled, this percentage slowly decreases until cleaning of the filter membranes becomes necessary.

Types of ultrafilter construction used in E-coat systems include spiral-wound, shell-and-tube, plate-and-frame and hollow-fiber multiple-tube. Each has advantages and disadvantages that should be examined by those considering E-coat systems. Individual preferences and preventive maintenance patterns seem to be as significant as operational and performance factors.

Ultrafilters must be properly maintained because good ultrafiltration requires a sufficient flow rate through the filter elements. In many instances manufacturers suggest flow rates of at least 35 gallons a minute to prevent fouling of the thin filter membranes. A thorough rinse of the parts after pretreatment will help avoid
bringing contaminants into the E-coat bath because the contaminants reduce permeate generation. It is inevitable that some insolubilized resin molecules will not deposit but remain in the bath. These will gradually clog the pores of the ultrafilter membranes.

Depending on throughput rates, normal cleaning of cathodic E-coat ultrafilters may be required at intervals of six to 20 weeks. In normal production the ultrafilter permeate output slowly decreases. When permeate generation falls to 80% (approximately) of initial output levels, the ultrafilters must be cleaned with a mixture of solvents and concentrated solubilizer solution. Cleaning ultrafilters frequently minimizes rinsing problems. Extending the interval between cleaning is an invitation for E-coat trouble. If cleaning is postponed too long, permanent impairment of ultrafilter function can result, especially with hollow-fiber and multiple-tube ultrafilters. Flat-plate and spiral-wound types may survive this neglect. However, even these ultrafilters should have regular cleaning as soon as their output diminishes to a designated level.

After the ultrafilter rinse, the parts may undergo further rinsing with deionized water to ensure that all contaminants are removed prior to baking. The deionized water rinsing is usually in two stages: a recirculating rinse and a final virgin rinse.

Figure 9-7. Bank of Ultrafilter Cartridges in a Large E-Coat Installation
The final fresh deionized water rinse of about 2 gallons a minute can flow into the recirculating deionized rinse tank, which can overflow either to drain or into a permeate rinse tank. A large amount of deionized water is needed to prepare the E-coat bath and provide the final rinses. Many companies insist that the drain-off deionized rinse in the pretreatment section have a maximum conductance of 30 micromhos to prevent contamination of the E-coat bath and of the system’s ultrafilters.

Solubilizer-deficient makeup resin is added to the E-coat tank through bath recirculation entry injection ports called “eductors” located along the sloped exit end of the tank. Figure 9-8 shows how replenishment materials are added to an E-coat system, and figure 9-9 shows banks of eductors at the bottom of an E-coat tank. Adding the makeup resin in this way helps prevent fouling the ultrafilters, compared to when makeup is introduced into the intake of the circulation pump. The eductor entry method ensures thorough mixing of the makeup material.

Before the solubilizer-deficient makeup enters the bath, it must already have been fully solubilized. This is essential because even tiny amounts of unsolubilized resin will quickly plug the ultrafilters and sharply curtail the production of permeate rinse.

The bath content must be monitored closely for the buildup of excessive chemicals that can interfere with efficient E-coat operation. For example, an excess concentration of ions in the bath can raise conductivity and interfere with
electrical efficiency. To prevent such buildups, a small amount of permeate is
normally released to drain continuously and replaced with an equal amount of
deionized water. Excess solubilizer, contaminants from pretreatment baths and
water hardness salts are released to drain also in the discharged permeate. Excess
solubilizer in the permeate rinse can resolubilize the freshly deposited paint film, in
effect stripping off the film immediately after application.

Figure 9-9. Illustration Showing Eductor Entry Method
Using Eductors at Bottom of Tank to Ensure
Thorough Mixing of Makeup Material

Pigments

The pigment particles are mixed uniformly throughout the bath by vigorous
circulation. During the E-coat process the pigment particles become entrapped
among resin molecules as the resin is attracted toward and being electrodeposited
onto the parts. E-coat pigments never undergo any change in electrical charge;
they remain uncharged throughout the process. Only the resins are converted from
a soluble ionic state to an insoluble neutral form.
Bath Parameters

An E-coat bath needs to be monitored closely to ensure quality coating deposition. Meticulous records should be kept of the following parameters:

- Percent total solids
- pH
- Solubilizer concentration
- Solution conductivity
- Temperature
- Relative amounts of pigment and binder
- Film build levels
- Voltage and amperage

The pH for many cathodic systems is held at a slightly acidic level of 6.0 to 6.5. Some other systems, especially those that eliminate excess solubilizer primarily by flushing ultrafiltrate to drain, may have a pH as low as 3.0 to 3.5.

A bath sample must be titrated periodically to check the concentration of acetic acid solubilizer. The concentration is usually expressed in units of “milliequivalents per liter of bath material.” A typical operating solubilizer concentration is 90 milliequivalents per liter.

Overall conductivity affects the electrical efficiency. If it is too high, efficiency drops. Normally the maximum of roughly 900 micromhos bath conductivity is appropriate.

The substantial amount of direct current used tends to raise the temperature of the bath because of the conversion of electrical energy to thermal energy. Chillers and heat exchangers are used in the circulation system to maintain bath temperature in a normal range of 70 to 95°F. Excessively high temperatures can cause difficulty with the ultrafiltration process and deteriorate the bath.

As resin and pigment are removed from the bath and deposited as a paint film onto the parts being coated, additional resin (presolubilized with acetic acid) and pigment must be added. Sometimes the resin and pigment are replenished in a single concentrate; however, since the resin and pigment may be used up at different rates as they deposit on the parts, it may be necessary to add each separately. Paint supplier assistance in monitoring the resin and pigment levels and in establishing the correct pigment-to-binder ratio is usually available. Improper ratios can quickly and easily be readjusted by the appropriate makeup composition.

Continuous circulation and filtering of the bath are necessary to prevent pigment settling and to keep the bath clean to avoid the deposition of foreign contaminants along with the resin and pigment. Pumps circulate the bath at a rate of four to six turnovers per hour. The bath is taken from the area behind the weir (an adjustable dam to control the level of the paint in the tank) and is then filtered. The paint is next fed back into the tank along the bottom through a series of pipes...
fitted with eductor nozzles. The jet force out of the nozzle orifices and the venturi action of the eductors on the surrounding bath help prevent pigments from settling and maintain good pigment dispersal in the bath. Eductors produce a mild scouring action that also reduces the amount of residue that can accumulate on the bottom of the tank. If adequate circulation is not maintained, extremely hard resin/pigment aggregates can build up on the tank bottom. As much as 14 inches of deposit have been found in E-coat tanks due to grossly neglected circulation problems. Parts that fall off the conveyor should be removed immediately from the bottom of the tank so that dead circulation spots are not formed that would contribute to residue.

**Tank Details**

The E-coat tank must be large enough to hold the parts to be coated and the necessary quantity of bath. Some tanks hold as much as 120,000 gallons. To paint continuously moving parts on a conveyor line, the tank must be considerably longer than for parts held stationary. A conveyor line operating at 14 feet per minute requires a total tank length of roughly 50 feet, including the portions used for gradual part immersion and withdrawal.

Anodes are located vertically along both sides of the E-coat tank. In some systems each anode is enclosed within a flushable cell. These enable continual flushing to remove excess solubilizer produced by electrochemical reaction at the anodes. Tubular (5 inches in diameter) or rectangular (6 by 24 inches) membrane cells of the needed length can be employed, but the ease of handling makes the tubular type increasingly popular.

**Voltage at Tank Entry**

Several options are available concerning the application of E-coat voltage as parts are immersed and after full immersion. These are as follows:

- The voltage can be turned off during parts immersion. This is called “cold or dead entry.” After the parts are fully immersed, the voltage can either be raised gradually to the specified level or be applied to that level all at once. Raising the voltage gradually after immersion will bring a slow, even and optimum deposition of paint film. Applying full voltage suddenly after full immersion may cause “current spiking” and the formation of excessive hydrogen gas at the part surface, which can interfere with even paint film buildup, causing what is termed “film rupture.”

- The voltage can remain fully energized before parts begin to be immersed, during immersion and after immersion. This is termed “hot or live entry.” As a
part is being immersed during hot entry, a paint film buildup begins on the wetted portion of part surfaces. Part surfaces under immersion the longest will have the greatest film buildup. Sometimes this progressive film buildup can leave what is termed “hashmarks” or noticeable lines of distinct film buildup around the part, which can become pronounced if the conveyor movement is jerky during immersion.

Two systems are used to lower parts into the E-coat bath: a hoist and an overhead conveyor. In the hoist type, a single part is lowered into the E-coat tank, which isn’t much bigger in length and width than the dimensions of the part. After a specified bath deposition time, the part is raised and advanced to the next stage, the cycle being repeated with another part. With this type of system it is relatively easy to have cold entry and raise the voltage gradually for optimum paint film buildup.

With the overhead conveyor system, the tank will have a narrow width but an extended length, which may permit a relatively large number of parts to be immersed at any given moment. To eliminate mechanical complexity, this type of system usually has hot entry, and the bath electrodes are generally spaced equidistant along each side of the tank. Some systems wire the power supply so that the first few electrodes near the tank entry have reduced voltages so that the parts do not come near an electrode with full specified voltage until a predetermined time after full immersion. Other systems omit electrodes near the bath entry to permit a gradual paint film deposition both during and immediately after parts immersion.

Because E-coat applied power may exceed several hundred volts and hundreds of amps, an E-coat tank during production is extremely hazardous. A person falling into an energized E-coat bath could be instantly electrocuted. A protective safety enclosure around the tank is necessary to prevent entrance by unauthorized personnel.

**E-coat Curing Cycle**

The final E-coat step is oven curing of the deposited coating. Although low-temperature curing and even air-curing are possible, the most durable films require a moderately high-temperature bake to cross-link the resins in the binder. This is often in the order of 300 to 350°F for 12 to 25 minutes, depending on the design, configuration and heat capacity of the part being coated. Convection ovens are used almost exclusively for curing E-coat paints, although infrared ovens can be used as well.

**E-coat Advantages**

Some of the advantages of E-coat include:

- Coating thickness uniformity
Coating thickness uniformity. In electrical deposition systems such as electroplating and E-coat, the consistency of film thickness varies with the separation distance of the part being coated and the other electrode (or electrodes). Part surfaces closest to the charged electrode will receive the greatest film buildup, because these are high-current-density areas, where film thickness will always be the greatest. Properly positioned charged electrodes will minimize differences in deposited film thicknesses. The deposition power (throwing power) is usually sufficient to deposit at least some coating thickness into many hidden areas. Auxiliary electrodes can be positioned to improve throwing power into these areas. In many instances the edges of parts become the high-current-density areas and receive extra film deposition.

High production rates. E-coat is adaptable to very high production rates because of the fast film deposition that is possible. E-coat wheel lines have operated at a conveyor speed of 48 feet per minute.

Primer/one-coat options. E-coat can be deposited as a primer to add corrosion resistance and to serve as a base for a topcoat. The primers tend to be mainly epoxies; others include alkyds and polyesters. E-coat formulations—generally acrylics—also can be deposited as one-coat systems.

E-coat Disadvantages

- Substrate limitation
- Color change difficulty
- High cost to install
- Masking problems
- Sophisticated maintenance requirements
- Sanding/stripping difficulty
- Second coat restriction
- Air-entrapment pockets
- Bulk small-part coating difficulty
- Corrosion-resistant equipment requirement
- Conveyor stoppage problems
- Deionized-water requirements
- High energy demand
- Restricted to large volume finishing
- Coating thickness limitation
Substrate limitation. E-coat cannot be used for plastics, wood or other low-conducting and nonconducting materials. Even some high-silicon-containing aluminum alloys cannot be used due to lack of electrical conductivity.

Color change difficulty. Color change for most installations is very slow. This is why more than 95 percent of E-coat installations paint only a single color. Quick color change requires a separate tank for each different shade when multiple colors are used. This is not generally the method of choice for economic reasons. The plants that change E-coat colors usually pump out the old bath into an agitated holding tank, clean the coating tank and ancillary equipment and then fill the tank with the new color material.

High costs. The initial capital cost and the continuing operating costs are extremely high when compared with simple systems such as dipping and spraying.

Masking problems. Since E-coat is an immersion process and requires a subsequent high-temperature bake, the masking requirements are unique. Masking tape, plugs and caps must be resistant to the E-coat bath and to the oven temperatures.

Sophisticated maintenance requirements. Because of the complexity of an E-coat system, sophisticated maintenance is required. Careful maintenance records must be kept; testing must be done on schedule. A pint sample of the E-coat bath is usually sent to the paint supplier biweekly or monthly for detailed testing. Color corrections may be needed on a daily basis.

Sanding/stripping difficulty. Because of the hardness of the deposited coating, it is extremely difficult to sand E-coat rework. It also can be difficult to strip E-coat paint from hooks, hangers and parts baskets.

Second coat restriction. A coated part cannot be run through an E-coat tank for another coating. The deposited paint from the first deposition will act as an insulator to prevent deposition of another coat over it.

Air-entrapment pockets Since E-coat is a dip process, it can be subject to coating voids due to air entrapment in “pockets” of the parts. A part that tends to form air pockets when immersed may need to be redesigned. Sometimes a conveyor oscillation system is employed to eliminate the air or to move the air back-and-forth.

Bulk small-part coating difficulty. Bulk E-coating of small parts can be done, but it tends to require a complex system. Only a few bulk E-coat systems have been built due to the inherent problems of operation.

Corrosion-resistant materials requirement. Because of potential rust problems, it is often necessary to use corrosion-resistant materials for E-coat tanks, piping, valves, heat exchangers and other components that contact the bath. Acidic cathodic paint can slowly dissolve metal parts.

Conveyor stoppage problems. The nature of the deposited E-coat paint film and the ultrafiltrate rinse requires exacting conditions in the E-coat postrinse. If the conveyor stops, coated parts in the ultrafiltrate rinse may be adversely affected.
The unrinsed bath solids will dry within 5 minutes and then cannot be rinsed off. Manual rinsing must be initiated if the conveyor stops for more than a minute or two. Similarly, E-coated parts that remain submerged in the E-coat tank during a line stoppage of more than 5 minutes can undergo paint film degradation.

High deionized-water purity requirements. The deionized water quality must be high. Its conductivity should not exceed 25 micromhos; the resistivity minimum should be about 40,000 ohms/centimeter; and the soluble salt content must be no greater than 10 parts per million.

High energy demand. The E-coat process requires a significant amount of electrical energy.

Large-volume suitability. Because of the elaborate equipment that is required, E-coat is generally suited only for large-volume finishing.

Coating thickness limitation. An E-coat film thickness is limited to about 0.5-1.5 mils. After this thickness is applied, the coating acts as an insulator to prevent further deposition. Maximum thicknesses vary widely among E-coat paints.

**Autodeposition**

Organic paint films can be deposited onto iron and steel parts by an oxidation-reduction precipitation process known as autodeposition, chemiphoretic and Autophoretic coating. The process, which uses no external source of electricity as with E-coat, is available primarily in black, although several colors such as brown, orange and light blue have been reported. The paint film has a dull or low-gloss appearance and is primarily protective and not decorative. The largest application areas for autodeposition coatings have been nonappearance and under-hood parts for cars and trucks. Excellent anticorrosion properties and the black color make it highly appropriate for this application. It is also used on drawer slides for office furniture, replacing zinc-plating.

An important advantage of autodeposition is its 100 percent coverage of all surfaces of a part that are wetted by the coating bath. Faraday cage areas, which hinder E-coat deposition, are nonexistent with autodeposition.

Figure 9-10 shows the main process stages in an autodeposition system. The process begins with a heated aqueous alkaline spray cleaning for about 1 minute at 160°F. Then a dip cleaner follows for 1 to 3 minutes at 185°F. Thorough cleaning is extremely important because the process tends to be especially intolerant of contaminants. These cleaners are the only stages in the entire process that are heated; the others operate at ambient conditions.

After multiple rinses, ending with a deionized water rinse, the parts go into the autodeposition bath for about 2 minutes. The bath, typically held at 68 to 72°F, is a waterborne material containing about 10 percent of a vinyl emulsion, hydrofluoric acid and hydrogen peroxide. The coating deposition reaction is nonexothermic (does not give off heat), and the rate of deposition slows as
increased coating covers the steel surface.

Coating deposition begins immediately upon immersion of the parts into the bath, which is maintained at a pH of 2.5 to 3.5. After about 2 minutes, 0.75 to 1.0 mil of coating is deposited. Hydrofluoric acid etches and removes iron ions from the part by chemically attacking the steel surface. Hydrogen peroxide converts the solubilized iron ions from the +2 to the +3 (ferrous ion to ferric ion) oxidation state. The iron +3 ion combines chemically with the vinyl emulsion polymer to form an insoluble resin that precipitates onto the surface of the steel. Even after parts are removed from the bath, unreacted resin is soon insolubilized by the continuing chemical action. Thus no unreacted paint needs to be rinsed from the parts. The inorganic chemicals remaining on the parts are removed from the paint film by a 30-second water immersion rinse. Figure 9-11 shows automotive brake parts emerging from one of the baths in an autodeposition process.

After the coating is deposited, several options exist. One option is the use of a dilute chromic acid rinse, followed by an oven bake at about 250°F for 15 minutes. Another option is to cure the coating in water at 180°F for about 8 minutes. The water cure tends to yield a coating with less corrosion resistance than a coating cured in the hotter bake oven temperatures. A water cure may or may not be preceded by a chromic acid rinse.
An autodeposition coating cannot be recoated by a second autodeposition process because no exposed steel is left for the acid to attack. A major advantage of autodeposition is that no organic solvents are needed and that no VOC is emitted. Autodeposition is used both by product manufacturers and a few custom-coating shops. The current process works only on ferrous metals, but a new autodeposition coating for zinc is in the late development stage.

Figure 9-11. Automotive Brake Parts Emerging From Autodeposition Bath
Chapter 10

How Paint Is Applied

Part 3

Air-Atomizing Spray Guns

The methods of paint application described in the two previous chapters rely on various forms of spreading or dipping. Each has unique advantages and disadvantages, and one or the other can be a perfect choice for a particular end use.

Another method of applying paint is by atomizing the paint into tiny mist-like particles and depositing them onto the surface to be coated. If a sufficient number of the particles is applied, they will create a continuous coating. Paint can be atomized in various ways. The most common is with the air-atomized spray gun.

The essential components of an air-atomizing spray gun are:

- Gun body
- Fluid inlet
- Fluid nozzle
- Fluid needle assembly
- Fluid control assembly
- Air inlet
- Air nozzle
- Air valve
- Fan control
- Trigger

**Gun body.** The gun body consists of the handle for the operator to grip and the barrel. The main thing that the almost countless models of air-atomizing spray guns have in common is a handle designed for operator hand comfort. The handle and barrel house the gun’s various components.

**Fluid inlet.** The fluid inlet is an opening, usually below the tip of the barrel, that allows the paint to flow into the gun. The opening is threaded to allow attaching either a siphon cup or a paint hose attachment.
Fluid nozzle. The fluid nozzle is a small device with a precision opening to permit the paint to flow out of the gun at a determined rate. One end of the nozzle is externally threaded and screws into the internally threaded barrel tip. An assortment of nozzles is available with different diameter openings.

Fluid needle assembly. This assembly serves as a needle valve to stop and start the flow of paint through the fluid nozzle.

Fluid control assembly. This allows the operator to start and stop the flow of paint through the gun by operating the trigger.

Air inlet. This is a threaded opening at the bottom of the gun handle to allow attaching a hose connected to a source of atomizing air.

Air nozzle. The air nozzle is a small device with precision openings that allows compressed air to be directed at the paint for optimum atomization. The nozzle, also called the "air cap," is internally threaded to attach to the externally threaded gun barrel tip. Air nozzles are available with many different configurations of openings to allow various atomization patterns. Air nozzles typically have "horns" with precision openings that can be directed to vary the spray pattern into a fan shape. Figure 10-1 shows the details of an air nozzle on a common type of spray gun.

Figure 10-1. Schematic of Common Type of Spray Gun
Air valve. The air valve gives the operator a means of controlling the flow of air through the gun.

Fan control. This control permits the operator to regulate air flow through the air nozzle horn openings to vary the spray pattern. Figure 10-2 shows how a spray pattern can be altered by varying the air flow to the gun's horn openings.

Opening the optional pattern control valve changes round spray pattern to widening oval shapes

Figure 10-2. Altering Spray Pattern by Varying Air Flow

Trigger. The trigger is connected to the air and fluid flow controls in the most commonly used “non-bleeder” guns. Partial triggering activates just the air valve, and enables the operator to blow dust off parts before painting. In “bleeder” guns the trigger activates only the fluid controls; air flows even when the trigger is released. The trigger is conveniently located on the gun to allow finger control.

Compressed Air Supply

To prevent paint contamination, the air supplied to a spray gun must meet a number of requirements. The air must be:

**Dirt-free.** The air must be filtered to remove dust, lint and other dirt-type contaminants. The air is generally filtered at the inlet port of the air-compressing device, and again after oil and moisture removal.

**Oil-free.** Air compressors usually send out oil vapor with the compressed air because oil is used to lubricate compressor rotors. Such oil vapor is generally removed with an oil-absorbing coalescing filter.
Moisture-free. A phenomenon of air, moisture and temperature is that warm air contains more moisture than cool air, and that when air is cooled, moisture tends to be wrung out of the air in the form of condensation or water. When air is compressed it increases in temperature. Enroute to the spray gun, the air temperature drops, producing moisture condensation that must be removed from the air line. This can be accomplished with air cooling systems and water traps, or by chemicals that hold water by absorption and adsorption. Figure 10-3 shows the capability of deliquescent, refrigerated and desiccant air dryers to remove moisture.

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</tr>
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<tbody>
<tr>
<td>Deliquescent</td>
<td>+ 40 to + 70 F</td>
<td>3 to 8 gal/day</td>
</tr>
<tr>
<td>Refrigerant</td>
<td>+ 35 F</td>
<td>2 gal/day</td>
</tr>
<tr>
<td>Desiccant</td>
<td>− 40 to − 100 F</td>
<td>0.04 gal/day</td>
</tr>
</tbody>
</table>

*300 SCFM; 90 F; 100 psig

Figure 10-3. Dryer Performance Chart

Air can be supplied to an air-atomizing spray gun by either an air compressor or an air turbine. Air compressors are of various types, and may include diaphragm, rotary and reciprocating construction. The compressed air from one air compressor can be further compressed in a two-stage system. An air turbine is a fan-like device that is used to supply large volumes of air at low pressure.

Compressed air from air compressors is generally passed through an air regulator to maintain a steady pressure for the gun. For example, the air line pressure in a manufacturing plant may be 100 psi, but perhaps only 50 psi is desired at the spray gun. The air regulator would drop the pressure to 50 psi and maintain this figure even though the plant air pressure fluctuated.

Paint Supply

Paint to be fed to an air-atomized spray gun can be fed by gravity, siphon or pressure systems. In gravity-feed, as the name suggests, the paint supply is above the gun and feeds by gravity. The paint container must be covered to keep out dust and needs to be vented to allow paint to flow.
How Paint Is Applied — Part 3

Figure 10-4. Siphon Feed Spray Gun

Figure 10-5. Pressure Feed Paint Tank
Paint in a siphon cup is drawn upward into the gun because of a negative pressure produced in the siphon tube by the flow of compressed air. The cups come in various sizes ranging up to a quart. They need to be vented. Figure 10-4 shows a drawing of a spray gun using a siphon cup.

Because of the limitations of gravity- and siphon-feed, the paint supply system in predominant use is pressure-feed. Pressure-feed is of two types: 1) compressed air is applied to paint, in a pressurized container, forcing paint to the gun; and 2) paint is pumped to the gun, either in a “dead-end” system or in a recirculating system, by various types of pumps.

The pressurized container may be a cup that is mounted at the bottom of the gun, but is usually a “pressure pot” (tank) connected by a 5-10 foot flexible hose to the spray gun. Pressure pot sizes range from about 2 quarts to 50 gallons. Figure 10-5 shows a drawing of a pressure tank. Figure 10-6 shows the cross-section difference in an air nozzle for a gun using a siphon cup and one using pressure feed.

Paint can also be pumped to the spray gun out of any un-pressurized container such as a pail, drum, or tote tank. Paint pumps that supply air-atomizing spray guns are of three basic categories: reciprocating piston (single- or double-acting), rotary (cam or gear) and centrifugal. The pumps may deliver paint directly to a gun or to a circulating system from which paint can be piped to one or more guns.

The paint delivered to a gun is generally filtered to remove contaminants that might cause rejects if allowed to be sprayed onto a product. The micron rating of the filter must be high enough to permit passage of pigments and metallic particles.

**Gun Operation**

The rate of flow of paint through a spray gun is a function of the fluid pressure (driving force), paint viscosity, size of the fluid nozzle opening and the setting of the gun’s fluid control valve. The fluid pressure is set to deliver the correct amount of paint through an appropriately selected fluid nozzle. High-production requirements need high rates of paint flow to be able to apply sufficient coating on parts moving past the spray gun at conveyor speeds.

The degree of atomization in an air-atomized gun depends on how efficiently the atomizing air breaks up the paint particles. It isn’t the amount of air pressure alone that breaks up the paint particles, but instead is a summation of air pressure, air volume and the precise merging configuration of the air and fluid streams.

Air-atomizing spray guns can be categorized into two general types according to the volume and pressure of the atomizing air:

- Low-volume high-pressure (conventional)
- High-volume low-pressure (HVLP)
How Paint Is Applied — Part 3

Figure 10-6. Cross-Sections of Siphon Feed Vs. Pressure Feed

Figure 10-7. Exploded Drawing of Conventional Air Spray Gun
Low-Volume High-Pressure (Conventional)

This category of air spray gun has been known as “conventional” to distinguish it from the modified gun versions that have appeared over the last 30 years. Figure 10-7 is an exploded drawing of a conventional gun. Figure 10-8 shows a conventional gun being used. The gun was developed early in the 1900's and has remained essentially the same over the years except for refinement in gun construction materials and in the design of air and fluid nozzles.

Figure 10-8. Conventional Air Spray Gun in Use

These spray guns use compressed air from an air compressor. The air pressure may range to about 100 psi, and the air volume from about 3 to 25 cfm. The air volume tends to be low when using low air pressures and rises somewhat proportionately as the pressure is increased. The air pressure selected is tied in closely with the air nozzle that is used. The size of the openings in the air nozzle orifices must not deplete the air compressor capacity. The relatively high air pressure typically used with these guns gives exceptionally fine atomization and allows high rates of paint flow to meet high production requirements.

If the atomizing air pressure is too high, droplets as small as 5 microns in diameter may result and may create a fog that can decrease application efficiency. The greater surface area of tiny droplets will increase solvent evaporation, producing “dry” spray, giving the part being painted a dusty look.
High-Volume Low-Pressure (HVLP)

This category of air spray gun uses minimal atomizing air pressures, often below 10.0 psi, because certain regulations stipulate that air-atomized guns may not exceed this pressure.

HVLP guns are classified into two categories, depending on whether the air is supplied by an air compressor or a turbine. The type of gun that uses an air compressor typically works in conjunction with an air regulating device located in the air line or inside the spray gun itself to ensure that no more than 10.0 psi of air pressure reaches the gun tip. Figure 10-9 compares the air source for a conventional gun with an HVLP gun using a turbine. The HVLP gun can also be supplied by an air compressor. In this case a non-bleeder HVLP gun is used.

Both the air compressor and turbine types of HVLP guns are characterized by an air nozzle with a relatively large-diameter opening for atomizing air. At 10.0 psi the air compressor typically supplies 15 to 30 cfm. Turbine type HVLP guns are recognizable by the large-diameter air hose connecting to the gun. This is evident in the guns shown in Figure 10-10. Compressor type HVLP guns are usually not easily distinguishable from conventional (LVHP) guns.

An air turbine can typically put out about 200 cfm of air at 10.0 psi. This means that up to eight HVLP guns can operate off a single turbine. An advantage of a turbine is that its air output can be heated to as high as 180°F, which helps provide easier atomization by heating the paint in the end of the gun to lower the viscosity. An air heater would need to be used with the air compressor type of HVLP gun to provide the same heated air. Bleeder guns are used with heated air so that the tip of the gun remains warm.

The low atomizing air pressure of an HVLP gun tends to minimize the amount
Figure 10-10. Comparison of Air Hoses Used in Conventional Vs. Turbine Type Gun

of “bounce-off” paint fog and reduces the amount of atomized paint that is blown past a part to be painted as overspray. The improved transfer efficiency helps hold down operating costs by reducing paint waste. As the solids percent of paint is increased, the need to minimize overspray increases accordingly to hold down costs. However, such reduced atomizing air pressure tends to decrease the fineness of atomization, which reduces the finish smoothness capability. The low atomizing air pressure of HVLP guns also tends to require reduced paint flow to the gun, which limits production speeds.

Conventional and HVLP Advantages/Disadvantages

In summing up the differences in high- and low-pressure air-atomized spray guns, each category carries advantages and disadvantages:

- High air pressure
  Advantage: Excellent atomization permits fine finishes
  Advantage: High production rates can be accommodated
  Disadvantage: Extensive overspray wastes paint
  Disadvantage: The overspray increases booth cleanup costs
  Disadvantage: The overspray increases exhaust filter replacement costs
Disadvantage: The overspray increases waterwash reservoir treatment costs.

- Low air pressure
  Advantage: Minimal overspray reduces paint waste and increases transfer efficiency
  Advantage: Minimal overspray lowers booth cleanup costs
  Advantage: Minimal overspray cuts exhaust filter replacement costs
  Advantage: Minimal overspray decreases waterwash reservoir treatment costs
Disadvantage: Atomization may not be sufficient for fine finishes
Disadvantage: High production rates may not be possible

Spraying Techniques for Air-Atomized Guns

Proper spraying techniques with air-atomized guns is extremely important because of the cost of the paint being applied and the expense of having to rework reject parts. Good spraying techniques will minimize overspray and result in the correct paint application for optimum appearance.

Before a person begins to spray paint onto a product, a number of points should be reviewed. The spray gun should be clean and in perfect working order. It should yield a spray pattern with clearly defined boundaries.

A proper spray pattern is achieved with the least amount of air pressure for correct atomization and the minimum amount of fluid pressure to provide enough paint to meet production requirements.

Good spraying technique requires adhering to the following basic principles:
- The gun should be put in motion before the trigger is squeezed
- The gun should be kept a uniform distance from the surface being coated
- The gun should be moved across the surface to be coated at a uniform speed
- The gun should be triggered at the beginning and end of each stroke
- Each spraying stroke should be started at the same vertical or horizontal location on a particular product
- Each previous stroke should be overlapped by the same amount
- The same number of strokes should be used on identical product surfaces
- The final stroke on identical products should be ended at the same surface location
- For an optimum coating, the gun distance from the product surface being coated should be 6 to 8 inches. Moving the gun closer will increase the wetness and film build. Backing the gun away will decrease wetness and minimize film build.

Some general principles should be followed when spraying products with different shapes. For example, the ends of vertical flat panels should be sprayed first, followed by back-and-forth horizontal spraying, beginning at the top. Long panels should be sprayed this way in strokes up to about 5 feet wide. When edges are being sprayed, the gun should be aimed so that as much overspray as possible
lands on uncoated surfaces. Exterior edges should be sprayed first. Spray should not be directed straight into internal corners; each side of the corner should be sprayed instead.

Gun variables should be monitored closely while spraying. These variables are the paint flow rate, fluid pressure, paint viscosity, air pressure, fan pattern and distance of the gun from the work.

The evaporation rate of the solvent from the atomized paint particles moving from the gun to the product being painted needs to be considered. Excessively slow solvent evaporation will yield an applied coating that might be excessively wet and cause paint to run or sag on vertical surfaces. Excessively fast solvent evaporation can produce a coating that is too dry.

**Air Spray Advantages/Disadvantages**

Air spray can be suitable for a single-gun system applying only several ounces of paint per hour and can be equally suitable if scaled up for use by a system involving a dozen painters who are each spraying a quart of paint per minute working out of a common paint supply line. Air spray is readily adaptable to any size coating operation and rate of coating application.

Quick-disconnect fittings give a fast color change capability. Automatic color changers are also available, principally for use with multiple or automatic gun systems.

The readily interchangeable fluid nozzles and air caps permit the application of paints having a fairly wide range of viscosities. Heaters can be added to reduce the viscosity of highly viscous coatings. It is easy to regulate the air and fluid pressures at numerous points in the system.

The spray guns can be mounted onto various devices for automatic application. These can include reciprocators that move the guns back and forth or up and down as parts are conveyed in front of them, and robots that move the guns through programmed paths. Also, various rotational or indexing systems can be incorporated to move the part to improve application efficiency.
Chapter 11

How Paint Is Applied

Part 4

Airless Spray and Air-Assisted Airless-Spray

Airless Spray

In addition to using compressed air as a driving force in spray painting, another method of atomizing paint is to increase the paint’s fluid pressure in a spray gun and redesign the fluid nozzle so the paint is atomized without introducing a pressurized air flow. This type of spray gun is termed an airless spray gun.

The design of the airless spray gun is much the same as that of the air-atomized spray gun. The main differences are the elimination of the air inlet, air nozzle, air valve and fan control, all of which are unnecessary because of the absence of an air supply to the gun. Like the air-atomized gun, the airless gun also has:

- Handle and barrel
- Fluid inlet
- Trigger
- Fluid nozzle

Handle and barrel. These perform the same function as in the air-atomized gun: the handle allows the operator to grip the gun, and the barrel provides a support for the fluid nozzle and trigger.

Fluid inlet. On some guns this is located under the end of the barrel, and on other guns at the bottom of the handle.

Fluid nozzle. The fluid nozzle on an airless gun differs substantially from the fluid nozzle on an air-atomized gun. The airless fluid nozzle orifice is elliptical in


shape, but is rated in equivalent circular diameter, typically from 0.007 to 0.072 in. The orifice is beveled or fanned out at various angles, typically in increments from 10 to 80 degrees.

**Fluid control (off-on) assembly.** This starts and stops the flow of paint through the fluid nozzle. Some guns use a tungsten carbide ball and seat.

**Trigger.** This gives the operator a convenient means of operating the fluid control (off-on) assembly.

A duckbill device, shaped like its name, is mounted on the end of the barrel as a safety device. A duckbill is shown in Figure 11-1. It is designed to prevent the operator from accidentally touching the high-pressure paint emerging from the fluid nozzle. The paint stream exits the nozzle with great force and can penetrate the skin and cause serious injury.

![Figure 11-1. “Duckbill” Safety Guard for Airless Spray Gun](image)

**Paint Supply**

Paint is supplied to an airless spray gun typically by an air-driven reciprocating fluid pump. The pressure exerted by the pump is in proportion to the ratio of the area of the pump piston and the area of the air piston. For example, if the pump piston is 20 times as large as the air piston, and if 100 psi is applied to the air piston, then $100 \times 20$ or 2000 psi will be applied to the pump piston, or to the paint. Frictional losses lower the pressure at the gun tip, however.

Airless spray paint systems are of two types: dead end and circulating. In the dead end type, paint is pumped directly from a container to the gun. In a circulating system, paint is circulated from the paint container through a paint line continually, and the gun is connected to the circulating line. A fluid filter may be located just ahead of gun or elsewhere in the paint line.
How Paint Is Applied — Part 4

Gun Operation

Paint is pumped to airless guns typically at about 1200 psi, although this may range anywhere from 500 to 6,500 psi. When the paint exits the fluid nozzle at these high pressures, it expands slightly and is atomized into tiny droplets without the impingement of atomizing air pressure. The high velocity of the exiting paint propels the droplets toward the work being painted.

The width of the spray fan from the fluid nozzle is determined by the nozzle’s fan angle. With the gun tip 12 inches from the part being sprayed, the spray width (at the part being painted) may vary from about 5 to 17 inches, depending on the fan angle of the fluid nozzle being used.

It is the size of the orifice that determines the quantity of fluid sprayed, and the fan angle that determines the thickness of the coating. The same amount of paint, but over a different area, will be deposited by two nozzle tips having the same orifice size but different spray angles. Airless fluid delivery is high, ranging from about 25 to 75 ounces per minute.

Spraying Techniques for Airless Guns

Recommended spraying techniques for airless spray guns are nearly the same as for air-atomized spray guns. The basic difference relates to the high paint flow capability of airless guns and their absence of blowing air pressure.

The high paint flow requires a consistent spray procedure to prevent uneven paint film build and the associated problems of runs and sagging. It is extremely important in spraying to point the gun directly perpendicular to a surface and to move the gun laterally or vertically in motions that are parallel to the surface. Overlapping of the spray pattern between spraying strokes must be consistent to prevent fluctuations in film thickness.

The absence of pressurized air flow in the vicinity of the target allows airless guns to spray into corners and hard-to-reach areas. When air-atomized spray is directed into these restricted areas, the air flow builds a cushion of air turbulence that tends to repel the movement of atomized paint particles toward the target. Figure 11-2 compares the efficiency of airless spray with air-atomized spray in painting a product interior, such as a box-like part. The paint sprayed from an airless gun nicely penetrates the cavity; the airless spray gun has considerable atomized paint blown out of the cavity. Figure 11-3 shows the same thing happening to a lesser degree when comparing airless and air-atomized spray on a flat surface. The high air pressure associated with air-atomized spray (conventional) creates air turbulence and atomized paint bounceback. The absence of air pressure eliminates such turbulence and bounceback.
Air Spray On Internal Surfaces

Airless Spray On Internal Surfaces

Figure 11-2. Air Spray and Airless Spray Demonstrated on Enclosed, Box-like Products

Advantages of Airless Spray

The advantages of airless spray guns include:

- High rates of paint flow
- Relatively high transfer efficiency capability
- Gun-handling versatility
- Ability to apply highly viscous fluids
High rates of paint flow. The high fluid pressure and the availability of nozzle tips with various-size openings permit high rates of paint flow. This allows airless guns to be used advantageously on high-speed production lines or where surface areas are large.

Relatively high transfer efficiency capability. The availability of nozzles with various fan openings helps optimize application efficiency. The absence of blow air associated with the gun simplifies application.

Gun-handling versatility. The absence of an air hose improves gunhandling versatility. One less hose connected to the gun lightens the gun for improved maneuverability.

Ability to apply highly viscous fluids. Fluids too viscous for air spray guns are readily sprayed with airless spray guns.

Disadvantages of Airless Spray

The disadvantages of airless spray include:

- Relatively poor atomization
- Nozzle wear
- Fan pattern control
- Coatings limitation
- Tendency for tip plugging
- Skin injection danger

Relatively poor atomization. The atomization with airless spray is generally inferior to that obtained with air-atomized spray, restricting airless spray to
product applications that do not require super-fine finishes.

Nozzle wear. The great pressures used with airless spray delivers a high rate of paint flow through the nozzle, tending to enlarge the orifice, increase flow rates and change spray pattern characteristics. This is especially true at very great pressures and with paints containing high amounts of pigments and especially with abrasive-type pigments.

Fan pattern control. To change fan patterns with airless spray guns requires changing the fluid nozzle.

Coatings limitation. The generally small fluid nozzle openings limit the materials that can be sprayed to those that are finely ground. This rules out fiber-filled, heavily pigmented and similar materials.

Tendency for tip plugging. The small orifice of the nozzle is easily plugged during spraying.

Skin Injection Danger

Probably the biggest disadvantage of airless spray is the considerable danger of injecting paint through the gun operator's skin. The high fluid pressure creates a paint stream that can easily penetrate the skin if the gun is triggered directly against or close to the skin. Sprayers have accidentally injected paint into their fingers, hands, arms and other parts of their bodies. As a consequence, some have required amputation of fingers, hands and arms. Some have even died after their bodies went into shock from the injection.

When paint injection occurs, only a tiny opening may be noticeable in the skin. This can be deceptive, for the injury can be severe, despite the minor-appearing wound.

Total removal of such injected paint is extremely difficult. The body reacts to the injection by the formation of considerable amounts of fluid that may cause further tissue damage if the pressure is not relieved. Figure 11-4 shows a tiny airless injection injury at the end of a forefinger. Note the small entrance wound and that the entire finger is swollen and turning blue. To remove the material, the finger will need to be surgically opened throughout its length, possibly causing further nerve and tissue damage.

Physicians knowledgeable in airless spray paint injection recommend immediate surgical examination. Keeping the affected area immobile after an injection will minimize the spread of the injected paint deeper into the body. Physicians report that injections into a finger can work their way past the wrist rather quickly with physical manipulations. This obviously complicates the surgery and the recuperation period for the patient.

As an aid to preventing injection accidents, devices such as the duckbill have been helpful. The extremely high pressure at the gun tip decreases rapidly with
distance from the fluid nozzle. A pressure of 3000 psi at the tip will decrease to 200 to 25 psi an inch or two away. Safety tip guards should always be used. The safety on the gun trigger should always be activated when the spray operator moves the gun to a new location (and at similarly appropriate times).

Some manual airless guns are designed to be inoperable without the duckbill. However, sometimes operators will cut off the safety device because the tips of the duckbill sometimes collect paint that then drips onto newly painted parts. Using the duckbill is a small inconvenience for the greatly added safety that it brings. Even with the duckbill, operators of airless spray guns still need to use extreme caution. Spray operators should be reminded frequently that fluids under great pressure can be dangerous, as evidenced by the use of high-pressure water jets to cut thick steel plates.

Air-Assisted Airless Spray

The air-assisted-airless gun spray gun looks almost exactly like an air-atomized spray gun. The handle, barrel, trigger and tip look the same. An air hose attaches to the handle and a paint hose connects to the bottom of the end of the barrel.

But beyond the similarity in looks, the air-assisted gun is much different in operation. The difference lies in the amount of fluid and air pressures that are used. An air-assisted airless gun uses from about 150 to 800 psi of fluid pressure and only 5 to 30 psi of air pressure. The fluid pressure is far more than an air-atomized gun but considerably less than an airless gun. The air pressure is far less than a high-pressure low-volume (conventional) air-atomized gun, and, of course, higher than the airless gun, which uses no atomizing air pressure at all.
The major difference in gun construction between an air-assisted airless gun and an air-atomized gun is in the atomizing tip. The air-atomized tip incorporates a fluid nozzle and an air nozzle. The fluid orifice in the center of the tip is surrounded by a concentric atomizing ring of air. The air-assisted fluid tip delivers a flat fan spray of partially atomized paint. Jets of atomizing air, exiting from ports in small projections on each side of the tip (similar to the wings of air-atomizing guns), impact at a ninety degree angle into the spray. The air jets break up the large droplets and complete the atomization, “assisting” the airless spray process.

The tips are available with various size fluid orifices and fan angles. These may range from about 0.009 to 0.036 in. and 15 to 80 degrees. With only fluid exiting the tip, an air-assisted airless spray gun has a spray pattern with heavy fluid “tails” on each side of the pattern. The tails are eliminated by gradually increasing the air atomizing pressure. The overall pattern can be refined by varying the air flow from the shaping air ports located adjacent to the ends of the slotted fluid orifice. The choice of tips and air pressure selection variation permits achieving a spray width of from about 4 to 19 inches at a distance of 12 inches from the target.

The paint flow rate can be varied from about 5 to 50 ounces per minute by varying the fluid pressure. The selection of tip and fluid pressure would be determined by production requirements. Paint is typically delivered to the gun from an air-driven reciprocating pump with an 8:1 ratio of air piston and fluid piston size. Fluid control typically is with a ball and seat-type valve in the end of the gun.

**Air-Assisted Spray Gun Advantages**

The advantages of the air-assisted spray gun include:

- Low equipment maintenance
- Good atomization
- Varied fluid delivery
- Low bounceback
- Reduced paint injection danger
- High paint transfer efficiency

**Low equipment maintenance.** The reduced fluid pressures in comparison with airless spray cut down on pump and fluid nozzle wear.

**Good atomization.** The atomization quality of an air-assisted airless gun is rated as superior to an airless gun but not nearly as good as with air-atomized gun.

**Varied fluid delivery.** The paint flow rates can be varied considerably from about 5 to 50 ounces per minute.

**Low bounceback** The extremely low atomizing air pressure allows air-assisted airless guns to spray into corners and hard-to-reach areas better than with air-atomized spray.

**Reduced paint injection danger.** The danger of accidental paint injection into the skin is considerably less than with the very high fluid pressures used with airless
spray. However, the fluid pressure is still relatively high and therefore still requires
great caution on the part of the operator in order to avoid any chance of an
accident.

**High paint transfer efficiency.** With a low-end delivery rate of 5 ounces per
minute versus 25 ounces for airless, air-assisted transfer efficiency is even higher
than airless.
Chapter 12
How Paint Is Applied
Part 5
Electrostatic Paint Application

In spray application, the driving force that pushes the atomized paint to the part to be coated includes various combinations of fluid pressure and air pressure. In the electrostatic application of coatings, the small coating particles are given an additional driving force: an electrostatic attraction that is made possible by electrically charging the coating particles.

All types of coatings can be electrostatically charged. Each of the previously discussed spray methods—air-atomized, airless and air-assisted airless spray can be applied with or without electrostatic charging. In addition paint can be applied by electrostatically charged disk or bell rotary applicators.

The principles of electrostatic charging apply equally to liquid or to powder coatings; however, this chapter will deal only with the electrostatic charging of liquid coatings. Electrostatic powder charging will be covered in the chapter on powder coatings.

The Basics of Electrostatics

Sooner or later everyone has a personal encounter with static electricity and electrostatic charging. Who hasn’t experienced a small, yet startling, electrical shock in dry humidity after walking on a certain type of carpet and touching either another person or an object. Who hasn’t observed that after combing their hair, the comb can attract small pieces of paper? Who hasn’t noticed flashes of lightning?
These are all personal encounters with electrostatics. Scientists have discovered the following basic electrostatic principles:

- All matter is electrostatically chargeable to various degrees
- Matter with an excess of electrons is negatively charged
- Matter with a deficiency of electrons is positively charged
- Two objects with equal and like charges repel
- Two objects with unequal like charges or opposite charges attract

Keeping in mind these basic electrostatic principles, it becomes easy to understand what happens in the three examples of electrostatic electricity. In the first example the friction of a person's shoes moving across a carpet transfers an excess of electrons either to the person or to the carpet. The carpet and the person become oppositely charged. If the person fairly quickly (before the charge drains away) touches another person or a metal object, each of which has a neutral charge, the person's excess charge becomes neutralized or equal to the charge on the other person or object. Electrons flow from one object to the other to neutralize the charge, sometimes with a visible spark.

In the second example, when the charged comb is brought near to the neutrally charged pieces of paper, the difference in the charge on the comb and paper creates an attraction, and the paper is drawn to the comb. After making contact, the charges tend to become neutralized, and the paper will fall from the comb.

**Electrostatics in Painting**

In electrostatic painting, the atomized paint droplets pick up an excess of electrons, becoming negatively charged. The part to be painted is electrically neutral, making the part positive in respect to the negative paint droplets. The opposite charges set up an electrostatic attraction between the charged droplets of paint and the part to be painted.

With an electrostatic spray gun, the droplets pick up the charge from an electrically charged electrode at the tip of the gun. The charged droplets are given their initial momentum from the fluid pressure/air pressure combination. As the charged droplets approach the electrically neutral part, the charge tends to attract the droplets toward the part. This attraction toward the part reduces the number of droplets hurled past the part, increasing transfer efficiency. The attraction is so strong that some charged particles hurled past the part will curve, turn around and come back to the part (wraparound), as shown in Figure 12-1. This tendency actually allows electrostatic painting to coat the edges of a flat part and a portion of the side of the part away from the spray gun.

Charging of the spray gun tip is achieved by an electrical power supply that continuously provides a source of electrons. The electrons are pushed by the power supply to a needle-like electrode at the gun tip, as shown in Figure 12-2. With the
power supply energized, the excess of electrons leaks off the tip of the electrode to the air in the immediate vicinity, creating a charged cloud of air molecules. This is called the “ionized air cloud.”

When paint begins to flow and atomized paint droplets are hurled from the gun tip they must pass through the charged cloud. In doing so, the previously neutral paint droplets pick up an excess of electrons.
The electrical circuit is typically completed as follows: The part to be painted is suspended from a metal hanger attached to an overhead metal conveyor, which is electrically grounded since it is connected to the building's steel foundation. The negative side of the power supply is connected to the gun electrode, and the positive side of the power supply is connected to ground via the building's steel foundation. Thus, the electrons drawn from ground by the negative side of the power supply go to the gun electrode; to the droplets; to the part to be painted; to the conveyor; to the building's steel foundation; back to ground from where they started their journey. An electrical power supply can be viewed as a generator of excess electrons. No electrons will flow through the power supply until the external electrical circuit is complete back to electrical ground.

The gun's electrode is in the shape of a needle to help the excess of electrons from the power supply drift to the charged cloud. It is the nature of a sharp point or edge to easily allow electrons to drain away.

The rate of flow of electrons from a gun's electrode during electrostatic painting is small, in the order of 5 to 50 millionths of an ampere (5 to 50 microamperes). An ampere (or amp) is a unit of current flow and is a measure of the rate of electron flow. An energized 100-watt light bulb has about 1 amp flowing through it. A lightning bolt may have a flow of millions of amps. A part being electrocoated may draw 800 to 900 amps.

The force in an electrical power supply that provides the push for the electron flow is called voltage. A residential power outlet has about 110 volts. A bolt of lightning may have millions of volts. A typical electrostatic power supply for painting operates in the range of 30,000 to 120,000 volts (30 to 120 kV).

In electrostatic painting terminology, a building's steel frame is said to be "grounded." This is because the frame is either embedded into the ground or is physically connected to something that is. The term "grounded" means that the object is electrically neutral with respect to the ground (earth).

The secret of success in electrostatic painting is to be sure that the positive side of the power supply is grounded and that the part to be painted is grounded. The positive electrode of the power supply is hardly ever a problem because it is connected to ground by a tight mechanical connection such as a bolt or a soldered welded connection. The part to be painted may not be properly grounded, however, due to a poor electrical connection between the part and the hanger, the hanger and the conveyor and between the conveyor wheels and the conveyor I-beam. For efficient electrostatic painting, all of these connections must be electrically sound. If they are not, electrical current flow will be restricted, and poor electrostatic charging of paint droplets will result.

For top efficiency, the part to be coated should be the closest grounded object to the charging needle on the spray gun. The charged paint particles are attracted to the nearest electrically grounded item; and the larger the item, the greater the attraction.
Ungrounded objects in the vicinity of the charged gun electrode can accumulate electrons and pick up a considerable electrical charge. The charge buildup can then arc over (spark) suddenly if a grounded object is brought near. The intense heat of the arc may be sufficient to ignite a solvent-containing atmosphere found in a typical spray booth.

Paint buildup on hooks and hangers can act as an insulator and block the flow of electric current in the electrostatic circuit. The greater the paint buildup, the more severe the problem. If the grounding loss is only slight, wraparound may be only partially reduced. When paint buildup on hooks is heavy, the paint droplets that hit the part do not lose their negative charges. From the repulsion of like charges, the incoming negatively charged particles are actually pushed away by the negative charges already on the part. The result is thin paint; parts are produced with film builds that are below specification. Should complete loss of grounding be experienced, the danger of arcing becomes large, and fires can result. Numerous instances can be cited where fires have occurred this way. To ensure good electrical connection between parts and hangers, some plants use square rather than round rods for hangers. The rod is formed into a hanger so that a sharp edge meets the hung part to be painted. The sharp edge tends to cut through paint that may accumulate on the rods. Hangers should be regularly stripped or otherwise cleaned of paint buildup to maintain good grounding contact to the parts and the conveyor.

People in the vicinity of the charged electrode or the spray gun should also be grounded. Spray paint operators must wear leather-sole shoes to drain charges to ground and have a gloveless (bare) hand on the grounded spray gun handle, or a glove with its palm removed. These precautions will ensure that the operator never accumulates an electrical charge.

To complete the electrical circuit satisfactorily, the part to be coated must be an electrical conductor. This is essential to maintain current flow and prevent a charge buildup on the part, which would repel additional charged paint droplets.

The conductivity of the paint can affect the path of the electron flow from the gun’s electrode to the part to ground and back to the electrical power supply. Solventborne paints tend to be extremely poor conductors; waterbornes and some metallic paints are excellent conductors. This difference in conductivity, however, introduces a new phenomenon: The conductive paint can carry the full supply of electrons away back through the paint line to the grounded paint tank. If this occurs electrostatic painting is not possible. To prevent shorting (grounding out) the system through the conductive paint and the paint pot, the paint supply is isolated from ground by non-conducting plastic supports. While this isolation of the paint supply (isolated system) enables electrostatic application of conductive paints, it still permits electrons to travel back to the pressure pot, turning it into a very dangerous source of a potential high voltage electrical shock to persons in the vicinity. As a safety precaution with waterborne electrostatic spray, the paint line
and pressure pot are confined in a caged area. The poorly conductive solventborne paint does not transfer the charge back to the pressure pot.

To ensure that solventborne paint remains a poor conductor, paint formulators recommend using “nonpolar” solvents. “Polar” solvents tend to be conductive because of the nature of their covalent and ionic atomic bonds. Nonpolar solvents tend to be poor conductors. Examples of recommended nonpolar solvents are mineral spirits, VM&P naphtha, xylol, toluol and N-butyl acetate. Examples of high-polarity solvents are acetone, methyl ethyl ketone, isopropyl alcohol, methyl cellosolve, diacetone alcohol, ethyl alcohol, methyl alcohol and methyl acetate.

The electrical hazard associated with electrostatic conductive paint spray tends to cause some plants to limit it to automatic application where operators are not involved. A manual gun used with electrostatic conductive paint spray would carry the full power supply high voltage, but with the proper equipment it is possible to manually spray conductive coatings.

Recalling the examples of static electricity, the charging of the comb (after combing one’s hair) and a person’s body (after walking across a carpet) tends to be more pronounced in low humidity. This is because the highly polar water molecules in humid air readily accept electrons. Thus, humid air will tend to speed the leaking away of charges from the comb and from the person’s body. In the case of lightning, the air in the vicinity of a thunderstorm tends to be humid, increasing the tendency of a cloud’s charge to discharge to earth or to another cloud in the form of lightning.

Humid air in the vicinity of a gun’s electrode tends to increase electron flow also. This is why electrostatic painting is sensitive to humidity fluctuations.

The electrical shock and fire dangers inherent with high voltages used in electrostatic paint spraying have led to the development of devices to lower the voltage at the gun’s electrode when a person approaches or as the electrode approaches an electrical ground. This prevents electrical shock and eliminates the chance of a spark starting a solvent fire.

A number of patented protective systems are used by various equipment manufacturers in their power supplies as safety devices to restrict the total amount of current that can flow. Some of these current-limiting devices proportion voltage and current. If the current begins to rise, the voltage drops correspondingly. This is known as a “resistive” system. Figure 12-3 depicts how the voltage at the tip of a current-protected electrostatic gun declines to zero as electrical current flow increases. This occurs because the increasing current flow causes the device to decrease the voltage at the gun tip. A so-called “stiff” system maintains the voltage until a preset current flow limit is reached. At this point the circuit is tripped off. Generally stiff systems are not approved for use with manual spray guns but are appropriate for automatic electrostatic spray operations. Other sophisticated protective devices measure how fast the change in current draw occurs and can shut off all current almost instantly, even though current draw has barely begun to rise.
How Paint Is Applied — Part 5

Advantages of Electrostatic Spray

The advantages of electrostatic spray include:
- Transfer efficiency
- Edge coverage
- Wraparound
- Uniform film thickness

Transfer efficiency. It is a rule of thumb in paint spraying that electrostatics will increase transfer efficiency by 10 to 20 percent.

Edge coverage. Excellent edge coverage is achieved with electrostatics because electrons (and droplets with electrons) are attracted more strongly to edges than to flat surfaces, as shown in Figure 12-4. Sometimes this can be a mixed blessing. Occasionally so much paint is drawn to edges that they will undergo solvent popping in the oven due to excess paint buildup. At times edge buildup can be so severe that paint runs are caused. As would be expected, this is most likely to cause
problems on parts with vertical edges. Turning off the electrostatic voltage prior to the spray reaching the edges can avoid such runs.

Wraparound. The attractive force of electrostatics will to some extent draw paint droplets around to the back side of the parts, a phenomenon called “wraparound” or simply “wrap.” This reverse side coating will extend around on parts about 1 to 3 inches away from the edge, with dimishing thickness. Because of the wraparound effect, complete coverage of small or “C”-shaped parts is possible with few gun passes.

Uniform film thickness. A uniform coat is somewhat self-produced because the incoming paint droplets experience the best grounding where the paint is the thinnest. As the paint thickness builds, it forms an electrically insulating layer. Therefore, newly arriving paint droplets are attracted most strongly to areas on the part where grounding is best, that is, the spots where the paint is the thinnest, as shown in Figure 12-5. In this way excellent film thickness uniformity results.

Disadvantages of Electrostatic Spray

Although the advantages of electrostatic spray are impressive, the disadvantages also tend to be pronounced, and relate to:

- Gun construction
- Equipment cleanliness
- Faraday cage effect
- Conductivity
- Metallics
- Solvent selection

Safety/fire hazards. These are lumped together as a disadvantage because they
tend to go together. A high voltage is hazardous and can cause a spark that could ignite a fire in a solvent-laden atmosphere. Everything near the tip of the gun must be grounded to prevent accumulating electrostatic charges. This includes machinery, personnel and anything that can build up enough charge so that arcing of electrons to ground can occur.

The phenomenon of “capacitance” enables any ungrounded object that can conduct electricity to store extra electrons (at least temporarily). The better the conductor and the larger the mass, the greater the quantity of electrons that the object can store. Thus the human body and metallic objects can build up large amounts of static charges unless they are continuously grounded. The connection to ground provides a path for the electrons to flow from the objects. If ungrounded, charge accumulation can continue until suddenly the electrons jump to a grounded object as a spark. The energy of the spark as the electrons drain off in a minature form of lightning can be more than enough to ignite solvent fumes. For this reason spray gun operators should be cautious about ungrounded metal items on their person. Coins and keys in pants pockets, metal pens in a shirt pocket, metal buttons, large decorative metallic belt buckles and similar items can cause this danger, although in these cases the charge usually discharges through the fabric of clothing to the wearer’s body in a very noticeable shock.

In some plants operators are required to wear conductive safety shoes or to attach a conductive, carbon-impregnated rubber strap around one ankle above the
sock. The strap trails on a metal grate to make certain the sprayer is continuously grounded.

If the sprayer chooses to wear gloves during manual electrostatic spray, the gloves should either be conductive or have the spray-hand palm removed. The metallic handle of the gun is grounded through the power cable and will also ground the sprayer if the skin is in direct contact with the gun. Metal rings, watches and other jewelry worn next to the operator's skin will not accumulate electrons on a grounded sprayer.

Fire caused by improper operations during electrostatic application is not a rare occurrence. When the proper safety procedures are followed, fires will not occur.

**Gun construction.** Electrostatic guns tend to be bulky and delicate. The bulkiness reduces maneuverability; the delicate characteristic requires careful handling. The bulky feature is inherent with the long barrel. Except for the metal handle, electrostatic guns are constructed in large measure of nonmetallic materials. This is especially necessary where the needle electrode protrudes from the gun tip, which is physically separated from the handle by a long insulated plastic barrel. Nonconductive plastic is necessary so that these parts do not hold electrostatic charges and do not carry charges from the ionized air cloud around the needle electrode at the gun tip to the grounded handle. This avoids both arcing and shorting to ground.

Bulkiness is increased by the necessity of some electrostatic guns to have an attached high-voltage power cable. The higher the voltage carried in the cable, the bulkier is the cable. Some guns require the full high voltage to be brought to the gun. Others require a low-voltage cable and rely on electronics within the gun to step up the voltage. Other electrostatic guns do not require an electrical cable at all because an air turbine inside the gun generates the high voltage, as shown in Figure 12-6.

The needle electrode protruding from the gun tip can be damaged easily. Therefore the gun requires careful handling. A bent electrode will reduce the efficiency of the electrostatic charging.

In addition, the relatively soft plastic parts such as the fluid tip and air cap tend to wear and require frequent replacement.

**Equipment cleanliness.** Extra cleanliness is essential for efficient electrostatic operation. This is important for hooks, hangers and for the outer surfaces of the paint application devices. Dirt or oversprayed paint can form a conductive track on the surface of the plastic gun tip and barrel back to the grounded metal handle, thereby shorting out the system. Sometimes people think they are painting electrostatically, but because of accumulated overspray on the application device, the system actually is not applying paint with any appreciable electrical potential. Sometimes spray operators will turn off the power supply and use the electrostatic gun as a nonelectrostatic gun because no electrostatic charging appears to be taking place. When this occurs, the reason for the lack of charging taking place is
obvious every time: dirty guns (charge leaking to ground) and/or dirty paint hooks and hangers (charge not getting to ground).

**Faraday cage effect.** Electrostatic application is not able to coat recessed areas as well as nonelectrostatic. This is due to a phenomenon termed the “Faraday cage effect.” Charged paint particles always seek the nearest ground. Thus, when coating a recessed area, the charged droplets tend to be attracted toward the sides of the recession, and especially toward sharp edges that may be present, instead of traveling to the bottom of the recess. Nonelectrostatic manual touchup may become necessary to get coating into these problem areas. Faraday caging becomes severe at high voltages. Some degree of Faraday caging is inherent in electrostatic application and cannot be avoided. For this reason not all parts are suited for electrostatic application. This is particularly true for parts with complex geometries or that have sharp edges, points, deep ridges or cavities.

**Conductivity.** In electrostatic paint application the parts being coated must be conductive to complete the electrical circuit. Nonconductive materials, such as most plastics and wood, can be made conductive by the application (by dipping or spraying) of alcohol containing ionic organic salts or with water containing potassium and calcium chlorides. Surface conductivity is achieved by the ionic material remaining on the parts after the alcohol or water evaporate. Precoat
applications for conductivity are neither costly nor time-consuming. However, it is nevertheless an extra step in the painting process, and an operation to be avoided if possible.

**Metallics.** Metallic paint contains millions of tiny metal particles (usually aluminum flake or aluminum powder) that are mixed uniformly throughout. When metallic paint is atomized and applied without electrostatic charging, the particles tend to lie flat on the surface being coated. This flat orientation provides maximum metallic surface area for reflecting light, giving a bright, sparkly effect.

When metallic paint is charged electrostatically, most of the charge is held by the metallic particles, which are the most conductive portions of the atomized droplets. This extra charge tends to make the metallic particles stand on edge (instead of lying flat as in nonelectrostatic application). Standing on edge helps the particles release their negative charge. The edge orientation reduces the surface area of the particles that can reflect light, causing a noticeable darkening compared to surfaces painted nonelectrostatically, as shown in Figure 12-7.

Metallic coatings are used extensively on automotive finishes. Automotive metallic topcoats are usually applied on the assembly line with nonelectrostatic spray for the final color coat because it gives a brighter, more appealing

**METALLIC FLAKE ORIENTATION**

(*EXAGGERATED FOR EFFECT*)

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**Figure 12-7. Comparison of Flake Orientation in Nonelectrostatic and Electrostatic Application of Metallic Paint**
appearance to the finish. To a lesser extent it is also done nonelectrostatically because almost all automotive repair shops tend to use nonelectrostatic spray. If a car were given a metallic finish on an assembly line with electrostatic guns and then later be “spot” repaired in a body shop with nonelectrostatic guns, the sparkle appearance of the repaired spot would be different in appearance from the rest of the car.

The electrostatic darkening effect of metal flake and the increasing economic and environmental desirability of electrostatic application have led some paint manufacturers to use mica flakes as a replacement. Mica, a complex sodium aluminum silicate identical in chemical composition to asbestos but with none of the health hazards, is a nonconductor and does not sink into the wet film or orient itself on edge as do metal flakes. This prevents mica flakes from exhibiting darkening when applied electrostatically as with aluminum metallics.

Pearlescent effects can be achieved with mica. Pearlescence refers to the multiple-color rainbow-like appearance noticed in a thin film of oil on water.

**Solvent selection.** The solvent selection is considerably critical with electrostatic painting. The paint must be polar enough to accept electrons well. If the paint is too low in conductivity, the droplets are unable to gather electrons as they travel through the ionized air cloud, and the electrostatic effect is minimal. With “dead” paints, adding a minor amount of polar solvent can correct this shortcoming. However, this is rarely required. Nearly all coatings have no need for additional polarity. In fact, many high-solids paints are inherently almost too polar due to the high reactivity of the resin molecules. For this reason the preferred solvents for electrostatically applied paints are the nonpolar or slightly polar solvents. Paints that are excessively polar accumulate so much charge passing through the ionized air cloud that excessive difficulty coating into recesses is experienced.
Chapter 13
How Paint Is Applied
Part 6
Rotary Atomizers

This chapter deals with rotary atomization, which involves the breaking up of paint into atomized droplets using a spinning device. Instead of air or fluid pressure to atomize the paint, as with spray guns, rotary atomizers use centrifugal force. (Centrifugal force tends to project an object outward from the center of rotation.)

Some spray guns use electrostatic charging, and others do not. Rotary atomizers, however, always use electrostatic charging. With spray guns the electrostatic charging is not believed to have much effect on the actual atomizing; with rotary atomizers, electrostatic charging can play a key role in the atomizing.

Although all rotary atomizers are alike in that they feed paint to the center and hurl paint droplets off the perimeter of a spinning device, they differ in three principal ways:

- Shape of the atomizing device
- Rotational speed
- Mounting configuration

**Shape of the device.** Rotary atomizers are usually made from a quality steel and come in two basic shapes: disks and bells (cups). The disks are, as their name suggests, thin, relatively flat and round. They come in two diameter ranges, depending if their rotational speed is low or high. Low-speed disks have a diameter ranging from about 10 to 26 inches, and the high-speed disks, about 5 to 8 inches.

The bells are not, however shaped like a bell. Their shape more closely resembles
a cup, truncated cone or shallow sauce dish. The bells range in diameter from about 1 to 5 inches.

**Rotational speed.** The rate of rotation of low-speed disks is typically 900 to 8000 rpm. Figure 13-1 shows a low-speed disk painting room air-conditioner housings. Figure 13-2 shows low-speed bells, which rotate from 1000 to 10000 rpm, and feature shrouds to catch solvent flushing during cleaning and color changes. The rotation of high-speed disks and bells can be varied from about 10,000 to 60,000 rpm. Figures 13-3a, 13-3b and 13-3c show three different models of high-speed bells.

![Figure 13-1. Low-Speed Disk](image)

Summing up the difference between the low- and high-speed rotary atomizers, the low-speed units tend to be rather large and rotate fairly slowly; the high-speed rotaries tend to be small and spin very fast.

**Mounting Configuration**

Disks are mounted in a horizontal plane to a vertical shaft and rotational drive that is generally attached to a reciprocating device to move the rotating disk slowly up and down. Parts to be painted by a rotary disk are hung from an overhead conveyor that is looped around the disk, the parts being about 16 to 20 inches from the disk perimeter. The reciprocating stroke distance is determined by the length
Figure 13-2. Low-Speed Bells in a Paint Line

Figure 13-3 A, B, C. Three Different Models of High-Speed Bells
of the parts to be painted. Extremely long vertically hung parts, such as extrusions, may incorporate floor- and ceiling-mounted disks, each with a stroke about half the length of the parts being painted. Very small parts may require no reciprocation.

Bells can be mounted in a vertical or horizontal plane, or at any angle in between. They can be mounted in fixed positions, onto vertically or horizontally operating reciprocators or onto robots. If a reciprocator is used with bells, the stroke is determined by the size of the part being painted.

Whereas a disk requires parts to be conveyed around it, the bells can function somewhat like a spray gun and be aimed at the part being painted. This allows bells to be used with conveyors much like spray guns. The typical distance from the bell to the part being painted is about the same as with disks.

**Rotational Speed and Atomizational Fineness**

As a general rule of thumb, the faster the rotational speed, the greater the centrifugal force and the finer the atomization. However, two exceptions stand out:

![DISC SPEED VS. PAINT DROPLET SIZE](image)

*Figure 13-4. Droplet Size As a Function of Disc Speed*
rotational speeds below 2500 rpm and between about 5000 and 15,000 rpm. Figure 13-4 graphs atomized particle size as a function of disk or bell rotational speed. Figure 13-5 compares atomized particle delivery velocities and particles sizes for air spray guns and bells.

Atomization efficiency occurring with low speed rotaries is due both to centrifugal force and electrostatic charge repulsion. The centrifugal force isn’t great enough to hurl the paint off the perimeter in finely atomized droplets, but only as coarse particles of paint. It is the electrostatic charge that atomizes the paint to a finer droplet size. This is termed “electrostatic atomization.” Without the electrostatic charging, atomization is not effective enough to use low speed rotation to apply coatings.

Atomization quality on low-solids paints with low-speed electrostatic disks and bells is intermediate between the extremely fine atomization of air spray and that of airless spray. The low-speed rotary atomization was used very successfully on low-solids coatings for some years before EPA regulations brought about the development of high-solids coatings.

Atomization occurring at from about 5000 to 15,000 rpm tends to be extremely poor because the centrifugal force hurling paint off the disk forms string-like filaments instead of discreet droplets. The filaments tend to intertangle, further preventing good atomization. Above 15,000 rpm, long filament formation ceases, atomization efficiency increases steadily and atomization is accomplished almost totally by centrifugal force. The function of the electrostatic charge at these high rotational speeds is mostly to place a charge on the atomized droplets so they will be attracted to the grounded parts to be painted.

High-solids and waterborne paints are difficult to atomize at slow rotational speeds because of their high surface tension. High-speed disks and bells are almost always operated at above 20,000 rpm to ensure a fine atomization. The particular operating speed is selected for the product being coated, the characteristics of the paint being applied and the rate at which paint is fed to the rotor.

<table>
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<tr>
<th>METHOD</th>
<th>TYPICAL PARTICLE DELIVERY VELOCITY</th>
<th>AVERAGE PARTICLE SIZE</th>
<th>PARTICLE SIZE RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIRSPRAY</td>
<td>10 METERS/SECOND</td>
<td>3.0 MILS (DIAM.)</td>
<td>0.5 - 5.0 MILS (DIAM.)</td>
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<td>BELL</td>
<td>0.7 METERS/SECOND</td>
<td>0.8 MILS (DIAM.)</td>
<td>0.6 - 1.0 MILS (DIAM.)</td>
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</table>

Figure 13-5. Comparison of Particle Delivery Velocity, Average Particle Size and Size Range for Air Spray Guns and Bells
Paint Application

The atomized paint leaving a rotating disk is hurled outward in a 360-degree pattern. The droplets are guided to the parts to be painted only by electrostatic attraction. No directional air is forthcoming from the disk vicinity to guide the atomized particles. With electrostatic attraction as the only propelling force, the air in disk booths must be relatively calm. Strong air currents would tend to carry the atomized paint droplets away from the part to be painted.

With the bells, directional air concentric with the bell is used to reduce the circular size of the atomized paint particle cloud, helping the electrostatic attraction guide the particles to the parts to be painted. The air, varying in pressure from about 10 to 40 psi, is directed through a circular groove or series of holes around the bell perimeter. The air forces the atomized particle cloud into a smaller “doughnut” of droplets whenever a reduced pattern of paint delivery is needed. With small parts the shaping air helps considerably to guide the atomized particles to the target to avoid paint waste. The shaping air does not assist in atomization but only controls the size of the delivery pattern.

The disks and bells are insulated to accept the electrostatic charging voltage (about 100,000). As with electrostatic spray guns, the parts to be painted should be electrically grounded to establish maximum electrostatic attraction. The parts to be coated, being the nearest electrical ground, attract the electrostatically charged particles. The electrical circuit is completed as with electrostatic spray: The paint particles give up their charge to the grounded parts.

Configuration of the Disk System

Various arrangements are possible with disk systems to bring about painting of the total part. Only the side of a part facing the disk will be completely painted as it is conveyed around the disk. (The back will get some electrostatic wraparound.) Both sides can be completely painted by incorporating two reciprocating disks and having the conveyor loop around each in a “figure S” configuration. A circular part, such as a water heater jacket, can be painted all around by automatically rotating the part slowly on its hanger as it is conveyed around a single disk.

Flat parts to be coated by being conveyed around a disk must not be excessively long or else the leading and trailing ends of the part will receive less coating than the center. This is because the part must be conveyed around a circular path. The maximum length of a part that can be painted by being conveyed around a disk is about 5 feet.

Disk application booths are semicircular to circular in shape. Up to one half of the booth is open for the conveyor entry and exit. The entry and exit portions of the conveyor are linear but the conveyor circles around the disk. This configuration of
the conveyor yields a shape resembling the Greek letter omega, often called an “omega loop.”

The air exhaust from disk booths must be at a low intensity to prevent generating strong air flows within the booth, which could interfere with the attraction of the charged atomized paint particles to the parts being conveyed around the disk. The booths are of the dry-filter type; the lower portion of the semicircle wall of the booth consists of paint filters. Air is drawn in through the large booth opening and exhausted through the filters.

**Disk and Bell Rotation**

Low-speed disks and bells are spun by electric motors. The high-speed disks and bells, however, are rotated by an air-driven turbine. They operate on the same principle as a high-speed air-driven dental drill.

The high-speed rotary units require disk and bell systems of exceptionally fine quality. Bearings that support the rotation are of two types: mechanical and air. The mechanical bearings must be precision-machined and lubricated to withstand the high rotational speeds. Air bearings substitute a steady stream of air for the mechanical bearings, the air preventing the rotating element from touching the housing.

A frequent cause of high-speed rotating system failure is poor air quality. Insufficient filtration of the air and failure to replace filter elements on schedule will permit oil, moisture or particulates to gel or harden the lubricants in mechanical bearings. These contaminants can build up in air bearings as well and eliminate the thin cushion of air between the sleeve and the shaft.

The dynamic balance of high-speed bells with mechanical bearings is of crucial importance. Any abnormality can disturb the balance at high speeds and strain the bearings, shortening their life. These defects include nicks and dents caused by improper handling and uneven paint buildup. An imbalance with air bearings generally has no adverse effect unless it causes the rotating elements to contact the housing.

To preserve rotational balance, care must be exercised in handling and cleaning disks and bells. In some plants normal booth maintenance includes spraying most of the booth equipment with cleaning solvent. Other plants use a cloth and a pail of solvent to wipe rotary units. Either of these practices can cause problems by forcing paint buildup into the bearings. Solvent getting into the bearings will wash away the lubrication. Nearly all rotaries have an air barrier to protect the bearings from paint or solvent incursion. This should always be used during cleaning, but may not provide protection from pressurized solvent spray cleaning.

Automatic cleaning machines for the bells have been designed by several automobile assembly plants to avoid rotary atomizer damage. Nicks are easily put
into the delicate edge if it should be struck by a part on the conveyor or by a wrench when the rotary atomizer is being replaced or removed for cleaning.

Rotary System Operation

Paint is delivered to the spinning surface of rotary atomizers via delivery holes around the periphery of a smaller concentric inner cup.

Retractable flush shrouds can be used to collect color-change purges and solvent rinses on rotary bells. Collection shrouds for side-mounted bells are fitted with gravity drain lines; overhead-mounted bells use siphon tubes. Capture of paint and solvent during these operations reduces the plant’s overall VOC output and in many instances lowers maintenance costs significantly. Internal dump valves are used for line purges.

The rotational speed of high-speed bells slows when going from an unloaded condition to when paint is delivered. At a typical fluid flow of 10 ounces per minute, the reduction in spin speed is roughly 10%. For a fairly high fluid flow of 20 ounces per minute, the speed dropoff is about 20%. Depending on the paint being used and the particular application, the slowing could be a significant problem. The bell spin rate is set high enough so that the rotational speed reduction when paint is flowing is not a factor in atomization. Governors have been used to maintain rotational speed irrespective of fluid loading, but such devices are not commonly employed.

Bell spin speed will often affect atomization, pattern size and the distribution of metallic flakes. Rotational speed can affect color until a certain speed is reached, above which virtually no color difference is noticed.

Early disks and bells had no convenient fast method to monitor rotational speeds. Systems that permit digital rpm readouts of spin speed are now almost standard.

The spin rate of the bell can be continuously monitored in several ways. Two systems involve electronic speed regulation: one with fiber optic pickup and the other with magnetic impulse pickup. The latter type offers the advantages of extra durability and low cable replacement cost. A third method uses a rather simple dual-air-pressure system with a “high/low” setup. In this type two different air pressures are applied to the turbine. A high pressure is used when paint is being applied; a low pressure is used during nonpainting or bell “idle-speed” times. A dual-pressure system works well with stable fluid-flow rates. Electronic speed control is preferred for painting operations that require frequent on/off triggering, those demanding extremely fine finish quality or whenever fluid flow rates are varied.

Serrated (mechanically grooved) edges on some bells eliminate air entrapment “microbubbles” in the wet paint film. Entrapment of air is most likely to occur
with high-surface-tension coatings, including both waterbornes or high-solids. Serrated edges enhance atomization so that bells can be operated at slightly reduced rotational spin rates. Each serration line forms a paint filament to enhance atomization.

The fineness of atomization from a high-speed rotary depends on the paint viscosity, paint flow rate, rotational speed and electrostatic charging voltage.

Paint films applied by spray guns can take on a different shade of color from those applied by high-speed rotary atomizers. This is due to the difference in particle size and the velocities at which they are delivered to the part.

**Hand-Held Bell**

The bell rotary atomizers described so far in this chapter have wide use in applying finely atomized paint on industrial painting lines. These bell systems are mounted as permanent capital equipment; the parts to be painted are brought to them.

A portable bell rotary applicator is used, however, in office decorating painting. One widely used application is in repainting metal office furniture inside their office locations, as shown in Figure 13-6.

The portable unit has a rather long configuration but is surprisingly well balanced and easily maneuvered. The operator holds the unit perhaps 6 inches or so away from the part being painted, moving the unit slowly back and forth or up

![Figure 13-6. Portable Bell Rotary Atomizer](image-url)
and down in even strokes, or in circular strokes of 4-6 inches diameter all over the part.

The bell electrostatically charges the atomized paint particles. The operator connects a grounding clip to the part being painted, which enables the part to attract the charged paint. Protective canvas or plastic sheets are positioned around other parts in the vicinity and the floor to catch any overspray. The painting is usually done after hours. Air dry paint allows the parts to be dry and ready for use the next day.

The bell can only apply up to 5-6 ounces of paint per minute. This rate of flow is satisfactory for furniture repainting but is inadequate for industrial production line painting.

### High-Speed Rotary Atomizer Advantages and Disadvantage

High-speed rotary disk and bell atomizers have several important advantages:

- Fine atomization
- High-solids, waterborne versatility

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<td>AIR-ASSISTED AIRLESS</td>
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Figure 13-7. Typical Transfer Efficiency Ranges for Various Application Methods
• Viscosity flexibility on low VOC coatings
• Transfer efficiency

**Fine atomization.** The high rotational speeds and electrostatic charging voltage team up to do an exceptional job of atomizing paint into extremely fine particles to ensure a high-quality finish.

**High-solids, waterborne versatility.** High-speed rotary atomizers can apply high-solids and waterborne coatings with equal ease to low solids coatings.

**Viscosity flexibility.** The speed of rotation can be adjusted to compensate for coatings with varying viscosities, eliminating the need to add solvent to adjust viscosity in many cases.

**Transfer efficiency.** Fine atomization, electrostatic charging and minimal air turbulence in the vicinity of the rotary atomizer and part being painted ensure a high transfer efficiency. Figure 13-7 compares typical transfer efficiencies for the various types of spray guns with the rotary atomizers.

High-speed rotary atomizers have only one disadvantage. Although their capability to paint broad open surfaces is outstanding, the absence of air or fluid pressure to push the paint droplets to the target limits the ability to paint into Faraday cage areas. Manual touchup in these hard-to-paint areas is usually required.
In the 1960s a new painting technology was developed called powder coating. Instead of a wet paint, the coating as manufactured and applied is totally dry. Its constituents are practically identical to a wet paint except for the absence of solvent. Like a wet paint, it contains resin, pigment (if a colorcoat) and additives.

The nature of powder coating as a technology can best be understood by examining a particle of powder coating. It is likely to vary in size and shape. If it were a sphere, it would be about 0.5 to 1.0 mil in diameter. A close examination of the particle will reveal a composite of resin, pigments (if a colorcoat) and various additives. All components are homogeneous (fused together) because of the way powder coatings are manufactured.

In manufacturing powder coatings, exact amounts of resin, pigment (if a colorcoat) and additives are dry-blended. The blend is then heated to the resin’s melt temperature, turning the dry blend into a fluid-like mass. The hot melt is then extruded into a thin, flat sheet that is quickly cooled and flaked. A mill then pulverizes the flakes into powder of about the consistency of baking flour.

Melting and forming a homogeneous mass of powder coating ingredients prevents any possible component separation that might otherwise occur when the powder coatings are shipped or handled. Potential segregation into pigment-rich and resin-rich portions could result from particle size and density differences among the components.

Returning to the examination of a particle of powder, the understanding of powder coating becomes complete when an analysis is made of how the particle becomes a coating. If the particle is placed on a surface that can withstand heat, and the surface is heated to the resin’s melt temperature, the particle will flow until an equilibrium sets in. If a hypothetical “sphere” particle of powder 1 mil in diameter is heated to the melt temperature of its resin, the sphere will “collapse” and flow to a circular disk about 1.6 mils in diameter and 0.25 mil thick. The actual diameter and thickness would be functions of the rheology of the resin, but this assumption demonstrates the idea of the particle melting into an expanded but
shrunken-in-height mass.

If a surface is covered with a single layer of particles of powder, each a hypothetical sphere 1 mil in diameter, and the particles are heated to the resin's melt temperature, the spheres would sag to a continuous coating film about 0.7 mil in thickness. Each melted sphere would merge and become homogeneous with the neighboring sphere, forming a continuous coating.

During an actual powder coating process, however, it would be practically impossible to apply a coating only one powder particle thick. The particles almost certainly would pile up at least several high. Therefore, it is easy to see that the minimum thickness of a powder coating would be in the vicinity of 2 mils or so.

Nearly all of the resins used in wet coatings can be used in powder coatings. In practice, however, epoxies, acrylics, polyesters and polyurethanes are used the most. Materials such as nylon, Teflon and polypropylene can be used in powder coatings, although they cannot be dissolved or readily dispersed in liquid systems.

Resins used in powder coatings may be either thermoplastic (flows when sufficient heat is applied) or thermosetting (cross-links when enough heat is applied). Thermoplastic powders are sometimes called lacquers, and thermosetting powders, enamels. Thermoplastic powders tend to be used for functional purposes; thermosetting powders, for decorative applications.

When heated, thermoplastic powder coatings form a paint film by melting and coalescing, just as liquid emulsion coatings coalesce in forming a paint film. Thermosetting coatings, when heated, cross-link to form a paint film, just as do enamels. The crosslinking occurs between the main resin component and another resin component, designated as a cross-linker.

Powder coatings are packaged in cartons and drums of various sizes, depending on the amount ordered by the coater. Their weights may range from as little as 25 pounds to as much as 300 pounds or more. Each powder container is lined with plastic, which is filled and then sealed to keep out moisture.

Because all powder coatings require heat to flow into a paint film, substrates that can be powder coated must be able to withstand such heat, which may range from about 250°F to 500°F. These temperatures rule out the use of powder coatings on wood and most plastics, making powder coating primarily a metal finishing process.

Surface-preparation requirements for powder coating are generally the same as for liquid coatings. The degree of pretreatment needed tends to vary with end-use requirements both for powders and liquid coatings. End-uses for liquid and powder with severe requirements would need maximum cleaning, a good conversion coating and a quality sealer rinse. End uses with low requirements could get by with minimal pretreatment. However, because powder coating films tend to be thicker than wet coating films, powder coatings can usually get by with less pretreatment than can liquid coatings. Some powder coating end-use requirements permit pretreatment to be limited to blasting with glass beads, aluminum oxide or steel shot.
Powder Application Methods

Successful powder coating application involves spreading the powder uniformly over a surface and applying heat to melt and flow the powder into a paint film. Two methods are used to do this:

- Electrostatically applying the powder and then heating the coated part to melt and flow the powder (electrostatic spray and electrostatic fluidized bed)
- Heating the uncoated part to above the powder melt temperature and then applying the powder, which immediately melts and flows (fluidized bed)

Electrostatic Spray

This is the most common method of applying powder coating. The part to be coated needs to be grounded. This is usually done by hanging the part onto a properly grounded overhead conveyor.

Powder in the bulk form needs to be “fluidized” before it can be “pumped” to a powder spray gun. Fluidizing is accomplished by placing a quantity of powder into a container with many perforations in its bottom. Air at a controlled rate is forced up through the bottom, gently agitating (fluidizing) the powder.

A venturi pump provides a means of drawing powder from the fluidized bed to the spray gun which charges the powder electrostatically and expels (sprays) the powder toward the target (part to be painted). Figures 14-1A, 14-1B, 14-1C and 14-1D show various products being powder coated. Air venturi pumps move powder from the fluidized bed to the gun, where metered air gently sprays the powder out the gun barrel. Figures 14-2A, 14-2B and 14-2C show a small powder supply tank and venturi pump, filling the tank and adjusting the fluidizing air.

The spray pattern is varied on some guns with a deflector and on others using air jets. Varying the deflector distance from the gun changes the spray pattern. Likewise, on deflector guns, the spray pattern is changed by varying the pressure of air introduced around the end of the gun barrel. Figure 14-3 shows a drawing of a powder gun.

Powder exiting the gun tip is charged electrostatically in ways similar to charging atomized liquid paint. The powder picks up extra electrons from an electrode (charged to 75 to 90 kV), becoming negatively charged. The charged particles are attracted to the closest ground, which should be the part to be coated. Some people believe that when the charged particles contact the grounded part, the high resistivity of the powder prevents the charge from discharging suddenly to ground. The charge “hangs on” and holds the particle to the part through electrostatic attraction. Figure 14-4 gives an example of this, showing some small powder coated parts emerging from a spray booth. The attractive forces are sufficient to hold the powder onto the part into the oven, where the particles melt.
into a fused coating.

Another explanation, and one preferred by this author, is that a “packing” effect occurs, which holds powder onto the parts firmly. This is why powder particles hold on well even in high humidities which would drain away charges very quickly.

A method of charging some types of powder without using a charging electrode is termed friction charging or “tribo” charging. A tribo gun is equipped with a grounded Teflon insert. Powder particles moving along the insert lose some electrons to ground, becoming positively charged to about 10 to 20 kV. Small amounts of adsorbed moisture on the particles facilitate the wiping off of electrons. The tribo charge generated in dry environments is often too weak to be effective. Tribo charging will not work with all powder coatings. Acrylic powders, for example, charge very poorly in tribo systems.

Tribo charging is often used as a means of overcoming the Faraday cage tendency for charged particles to avoid depositing in confined areas. Such areas rapidly build up a charge and repel the charged particles. Moderately tribo-charged particles can succeed in overcoming the Faraday cage problem. The same effect can be achieved by turning down the voltage in a conventional electrostatic power supply to 10 to 20 kV in many instances.
Figure 14-2. Photo A Shows a Powder Supply Tank and Venturi Pump; Photo B Shows Tank Being Filled; and Photo C Shows Adjustment of Fluid Air

Figure 14-3. Cutaway Drawing of Electrostatic Powder Spray Gun
Some powder coating systems preheat parts to various temperatures to help the film build. The higher the preheat temperature, the greater the tendency for applied powder to flow and to build film thickness. All powder coating lines with washers have dryoff ovens, which provide some part preheating prior to powder coating. In some instances selective heating is done to build film thickness in hard-to-coat locations.

Powder exits a gun very gently, forming a powder cloud through which parts are conveyed. Figure 14-5 shows lawn furniture emerging from a powder booth, the interior of which appears to be filled with a cloud of powder. The grounded parts moving through the cloud attract the charged particles. The amount of powder
attracted to a part depends on the charging voltage and the conveyor speed. A part being conveyed rapidly through a weakly charged cloud may draw only a light coating that would flow to a film thickness of about 1 to 2 mils. A part being conveyed slowly through a highly charged cloud could attract enough powder to build a film thickness of about 3.0-5.0 mils.

Almost all electrostatic spray powder coating systems apply the powder in confined booths. Powder moving past the part is drawn downward by a gentle downdraft air flow. The air flow must be moderate to prevent blowing the applied powder off the parts. Overspray powder reaching the booth bottom is returned to the fluidized bed to go through the gun again.

The downdraft air creates a negative pressure in the booth, bringing in air from outside the booth. Therefore the air in the vicinity of the booth must be clean and relatively dry to prevent drawing moisture and contaminants such as dust and lint into the booth.

The air returning the overspray powder to the fluidized bed container is exhausted through powder recovery filters and then through very fine (absolute) filters that trap the remaining ultrafine powder particles, preventing their entering the powder coating room atmosphere. Sometimes fabric bag filters, cartridge filters, or a “cyclone” is used to help recover overspray powder. Figure 14-6 shows a drawing of a cyclone and how the powder is recovered.

Changing powder coating colors in a conventional powder coating booth tends to
be complex. If only one booth is used, all surfaces of the booth and powder reclaim system must be purged of powder before a new powder is entered into the system. Figure 14-7 shows the amount of powder that collects in the interior of a booth that has been applying powder. All surfaces of the entire powder recirculation system accumulate powder in the same manner. Before applying a new color in a booth that has been applying powder, every trace of the previous powder must be removed. Any remaining particles of the previous powder will deposit along with the second color, giving a “salt and pepper” effect.

Various quick-color-change systems are used for powder. The most common uses separate booths for each color. This allows a booth to be moved on and off line as its color is needed. Another system has a booth with plastic walls that are rolled up after each color change. Figure 14-8A and 14-8B show a powder booth equipped with a floor conveyor and vacuum pickup device to somewhat simplify powder color changes.

Some powder coating users make no attempt to recover the sprayed powder. They collect all sprayed powders in a common container and either dispose of it or sell it to someone who can use a mixture of many different colors. Such a mixture
can be used on parts where appearance is unimportant.

The “transfer efficiency” of electrostatic powder spray needs to be defined. The percentage of powder attracted to parts moving through a charged powder cloud probably in the order of 50% (depending on part size and shape). Although this is true transfer efficiency, it is deceptive because most electrostatic spray powder coating systems recirculate and reuse overspray powder. If powder coating transfer efficiency is defined as the total percent of powder used, taking into consideration the recirculating and reclaiming of the powder, then the figure is around 95% or higher.

However, on systems that do not reclaim overspray, the transfer efficiency probably ranges from 20% for thin, spindly parts to perhaps as high as 55% for parts with large surface areas, such as panels.

Just as the downdraft air flow in the powder booth needs to be gentle to avoid blowing deposited powder from the part, so must exhaust and recirculating air in a powder curing oven be gentle, especially at the oven entry. As the parts heat and the powder reaches the melt temperature and begins to flow, the requirement for gentle air ends.

Figure 14-7. Interior of Booth Showing Accumulation of Overspray
Figure 14.8. Powder Spray Booth with Floor Conveyor and Vacuum Pickup Device

(a) Vacuum Pickup Head Collects and Conveys Powder to Small Cyclones (at left)

(b) Diagram of Continuous Belt with Vacuum Collector
To minimize air circulation, some ovens incorporate infrared heat at the entry. Gas infrared is usually less costly to operate, but temperature control tends to be slow and difficult. Electric infrared lamps or glow-bars are simple to install and to focus if supplementary heating is needed.

It is important that the powder be heated quickly to melt and flow the material before too much cross-linking has taken place. In this way smooth films will be produced. Post-cure quenching in water is rarely done, although at one time it was used to create smooth finishes with some vinyl and nylon powders.

**Fluidized Bed**

In fluidized bed powder coating, heated parts to be coated are dipped into the fluidized bed. Figure 14-9 shows a nonelectrostatic fluidized bed. Figure 14-10 shows an electrostatic fluidized bed. In most cases the powder in the fluidized bed is not electrostatically charged, and the parts to be coated are first heated to above the powder melt temperature prior to dipping in the powder. Figure 14-11 shows a heated part being dipped into a powder fluidized bed. Powder particles contacting the hot part immediately begin to melt and flow into a coating. The coating tends to be thick because all powder contacting the hot part will melt and adhere to the part.

![Figure 14-9. Heated Parts Coated in a Fluidized Bed](image-url)
Fluidized beds. Electrostatic fluidization is a technique that involves the use of high-voltage charged particles to fluidize a bed of particles. This method is particularly useful for small, fine particles that are difficult to fluidize using conventional means.

A charged particle is released from a fluidized bed powder immediately adjacent to the hopper to capture possible wandering particles. The powdered droplets on the fluidized bed are collected in an annular or annularly distributed pattern above the fluidized bed. The area of high surface finish of the fluidized bed is minimized (at 45 to 50%) per square foot of fluidized bed surface is typical. In the field of fluidized bed work, 28 F.  The fluidizing air must be free of oil and particulate matter and have a dew point below 140 F. The fluidizing air is supplied to the fluidized bed powder by a nozzle on the hopper. The nozzle is at least 6 inches from the fluidized bed and is positioned so that the powder is directed away from the fluidized bed. The fluidized bed is kept in a constant state of fluidization by agitating the hopper with a high-speed motor. The fluidization process is controlled by monitoring the fluidized bed temperature and adjusting the air flow as needed.
bottom of the hopper to add electrons to the powder. If the parts were to be immersed fully into the powder cloud, thick coatings would result. However, it is possible to utilize the attraction between the negatively charged powder and the grounded object to be coated. Electrostatic attraction will cause powder particles to be drawn out of the fluidized bed onto the part to be coated.

For small parts the major advantage in using electrostatic fluidized bed application is that thin coats are possible compared with nonelectrostatic fluidized beds using heated parts. Films of about 4 to 10 mils are applied this way.

Considerable amounts of fencing, screening and similar open-mesh coiled stock are coated in this fashion. Screening in coil form is run vertically up between a pair of fluidized beds. The powder is quickly fused and cured with infrared heat. The screening is then cooled and recoiled. Open-mesh and expanded metal materials can also be coated in coil form by vertical fluidized powder coating. Numerous small parts are powder coated on horizontal conveyors using an electrostatic fluidized bed. The parts must be small because powder cannot be electrostatically attracted out of the fluidized bed for distances of more than 6 to 8 inches. The powder is immediately cured with infrared or convection oven heat.
Specialty Powder Coating Methods

Small hard-to-rack parts can be bulk powder coated. Parts preheated on a metal belt fall into and then pass through a vibratory powder coating bowl from which they are fed onto a continuous belt and exposed to additional heat to fuse the powder. Automatic flip-over exposes both sides to curing energy so that no bare spots remain. The minimum film build by this method is 3 to 5 mils.

Some vertically reciprocating powder coating disk systems are in operation. As with liquid paint application, the disk is charged negatively at about 100,000 volts. The powder coating disk, however, does not rotate as do disks used to apply wet coatings. The high voltage on the disk charges the descending powder negatively. Since like charges repel, the powder particles are electrostatically forced radially outward to the disk edge. Powder particles leaving the disk are attracted to the grounded parts that are conveyed around the disk.

The powder coating disk is claimed to have the output equal to that of six spray guns. It is said to be capable of applying coatings as thin as half a mil with excellent thickness control, at least on parts that are fairly simple in shape. Normally the disk would reciprocate vertically, but it can also operate in a fixed position or be tilted slightly. Exhaust air requirements are identical to those for powder spray booths. Overspray powder is carried down to the bottom of the booth by a stream of air, and powder is recovered for reuse with the usual variety of filtering devices.

Attempts have been made to use powder slurries for electrodeposition coating, dip coating, flow coating and for spraying using ordinary wet paint application systems. To do this involves extremely fine grinding of powder and mixing (slurrying) the material in water. Unless powder is ground extremely fine, it separates too rapidly from the water slurry instead of remaining suspended. The economics of aqueous powder suspensions are not often favorable.

Advantages of a powder slurry coating is that films as low as 0.3 mil (dry film thickness) can be achieved. The reuse of the powder slurry overspray is rather difficult, if not completely ruled out. For a short time an E-coat powder slurry was used in an automotive plant, but the finishes were very rough and required excessive sanding.

Powder Coating Advantages

Powder coating’s rapid growth is no doubt due to its many advantages. After 25 years of use, powder coating captured about 16% of the industrial finishing market. This percentage is expected to grow steadily until it probably peaks at about 30-35% of the industrial finishing market. Powder coating advantages include:
Cost. The nature of powder coating allows various traditional processes on a finishing line to be omitted or reduced. These include:

- No solvent flash required. This allows shortening the length of the conveyor formerly used for flash time. Parts can enter the bake oven immediately after coating application.
- No coatings mix room needed. Powder coating lines have no need for a coatings mix room. Powders are completely formulated by the powder coating manufacturer for immediate application.
- Minimal oven length required. Powder coating ovens can be short in length. No gradual heatup is required to drive off solvent slowly to avoid solvent popping. Quick heatup is recommended for powder to avoid film roughness.
- Low ventilation requirement. The absence of solvent greatly reduces requirements for air makeup and exhaust.
- Floor space economy. A properly designed powder coating line requires from two-thirds to three-fourths of the floor space needed for wet painting systems.

VOC compliance. The absence of solvent and the practical elimination of VOCs make powder a certain compliant coating in the eyes of environmental regulatory agencies. The absence of solvents has a number of other advantages:

- No solvent odor. This is highly advantageous inside the plant for employee health considerations and outside the plant for eliminating a nuisance factor, which is especially important in residential areas.
- No solvent storage. The elimination of solvents foregoes the need for solvent storage, which saves space and reduces fire hazards.
- No solvent thinning. Since no solvent thinning is needed for viscosity control, fire hazard is reduced.
- Reduced insurance rates. The absence of solvents and the elimination of solvent fire hazards can reduce insurance rates. Powder in a dust form can explode. However, proper safety precautions can minimize this powder hazard. The fire and explosion hazard with powder is remote in normal operations.

- No solvent health hazard. Powder reduces the potential health hazards to the sprayers. Solvents can irritate the mucus membranes of the eyes. Powder spilled on the skin is not absorbed into the body and can be removed with a gentle stream of air or with a vacuum cleaner. Cleanup of skin with soap and water is also recommended and rapidly accomplished. An appropriate particle filter mask is recommended for safety when spraying powders, some of which contain toxic ingredients.

Powder coating quality. Powder coating has acquired a reputation for providing a quality finish. Powder coatings tend to be extremely durable and provide outstanding corrosion resistance. At equal film thicknesses, powder coatings are often superior to their corresponding wet finishes. One reason for this is the virtual absence of shrinkage in the cured powder coating film, which minimizes stress during curing. When wet films cure, the loss of solvent from the coating shrinks
the paint film, causing internal stresses. Powder coatings applied onto grit-blasted surfaces that have not been conversion coated are always far superior to wet paints on this type of surface, both in adhesion and in the corrosion protection afforded. Powder coatings can readily be applied thick for endurance coatings. Edge coverage tends to be excellent for powder.

**Powder overspray reuse.** Most electrostatic spray powder coating systems recirculate and reuse the overspray powder. This allows a utilization of about 95% of the powder. The only powder not recovered is the small amount lost during booth cleanup for color changes. This powder reuse practically eliminates disposal problems. Disposal of spilled or contaminated powder is relatively easy compared with disposal of wet paint sludge. Powder coating systems have no contaminated booth water to treat and no used dry filters from spray booths to replace and dispose.

Landfill sites are more likely to refuse to take liquid waste or to charge higher rates for such waste than for dry powders. This is especially true if the paint sludge contains organic solvents. Places for disposal of wet paint wastes containing flammable amounts of solvent are hard to find, raising disposal costs. Plants have paid from $300 to $1200 to dispose of each 55-gallon drum of wet paint sludge!

**Little operator expertise is needed to spray powder.** With wet coatings a great deal of spraying practice and finesse is necessary to get uniform coatings and avoid runs and sags. Some plants claim that a person without wet spray experience is often better at powder coating than a skilled wet painter. They point out that this allows using unskilled labor for powder coating application, bringing a lower labor rate, helping to reduce costs. Runs and sags, while not impossible to produce, are extremely rare with powder coatings. As long as enough powder is directed into the vicinity of the parts, the electrostatic effect tends to produce a uniform coating. When excess powder is directed at a certain area of a part, the powder simply falls into the recovery system.

Coverage is particularly good with powder coatings because of the added electrostatic attraction and because powder coatings exhibit very little edge pull. Powder spray patterns and the electrostatic voltage can be adjusted to produce uniform part coverage, even on parts with complex shapes. Voltage adjustment enables careful control of coating thicknesses. Spray patterns can be varied from a thin powder stream for covering deeply recessed and concave areas to a wide cloud to coat broad, flat surfaces. Automatic powder spray guns are readily engineered for high-volume production, and multiple-gun systems are abundant.

Powders can be selected that incorporate topcoat and primer properties all in one and can be applied in a single coating operation. In this way the separate primer and topcoat operations can be combined into one step.

**Energy savings.** Although powder coating systems require a dryoff oven after pretreatment and a powder bake oven, they still use less energy than wet systems. Energy for a dryoff oven can often be conserved by using waste heat from the bake
Powder Coating

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oven. Powder’s big energy savings comes from the greatly reduced air-exhaust and air-makeup requirements. Only about 10% as much air is needed for a powder booth as compared with a wet spray booth. Because no solvent vapors form in the powder booth, only enough air is used to recover overspray powder. The absence of solvent allows a powder spray booth to be filtered and exhausted into the plant. Powder’s requirement for a relatively small oven may save energy, but the bake temperatures tend to be somewhat higher than for wet paints.

**Powder’s quick “packageability.”** When a powder coated part emerges from an oven, it can be packaged when cool enough to handle. Unlike many wet coatings that continue to cure for days or even weeks, powder coatings develop a full cure during the bake process. As a result powder coated parts resist handling abuse immediately out of the oven far better than wet coatings. They are less easily damaged during handling and assembly operations, and they do not require as much care in packaging for shipment. Problems of parts sticking to the packaging because the powder coating is not fully cured do not occur.

**Resin availability for powder coatings.** Resins that are not available in solventborne systems due to limited or total insolubility in solvents suitable for use in painting can be used in powder coating. For example, nylon and Teflon powders are virtually unavailable in their pure form except as powder coatings. The same is true for polyethylene and polypropylene.

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**Powder Coating Disadvantages**

Although powder coating has numerous advantages, it also has a number of disadvantages. Probably its main disadvantage is the requirement for heat (about 300 to 500°F, depending on the type of resin) to flow and fuse the powder into a coating film. This pretty much restricts powder to being a finish for metal. In a few limited cases it has been possible to lower powder’s cure temperature to 250°F. For electrostatic application, powder coating also requires a conductive substrate, which again practically limits it to metal. Powder coating’s other disadvantages include:

**Powder manufacturing limitations.** Because of the way powder coatings are made (mix, melt, extrude, flake and mill), it is often not economically feasible to make small amounts. Powder manufacturers generally like to make a minimum of 1000 to 2000 pounds. A few powder producers specialize in preparing small-size orders, however, but usually at a cost premium.

One of the problems in manufacturing a new powder formulation relates to color matching. Exact powder color matching usually involves trial-and-error procedures, which adds to the “gearing up” costs. A considerable amount of raw materials may have to be used before the exact color is matched.

Color matching with powder starts at the beginning of the powder
manufacturing process. Mixing of powders is not the same as for wet paint. If a can of white and a can of red paint are mixed, two cans of pink paint are produced. If a box of white and a box of red powder are mixed, two boxes of a “white and red” powder will be produced. Even when it is applied and cured, the film would be a mixture of red and white. The colors do not mix together with powder as they do with wet systems. Minute amounts of cross-color powder coating contamination are often visible because extraneous color particles fail to blend.

Another powder manufacturing drawback is that wrinkle and texture finishes are limited. In preparing textured powder coatings, control of texture size and distribution is limited, unlike the wide variation possible with wet texturing.

Difficulties also exist in preparing metallic powder coatings. Powder coatings that contain mica, metal powder or metal flake cannot fully duplicate the attractive look and glamour of wet metallic finishes. This has kept powder out of the large automotive topcoat market. In North America about 70% of all cars produced have metallic paint finishes. The lack of “shrink” of the powder coating gives less metallic brilliance in the appearance of the paint film. Shrinkage of wet films as solvents evaporate forces the metal flakes into a predominantly parallel orientation to the substrate surface, known as metallic “flop.” A sharp brilliance results from increased reflection because of light striking a greater surface area of metallic flakes. However, recent powder developments have yielded metallic powder coatings that are excellent for many types of parts. One such development encapsulates the metallic particles before they are added to the manufactured powder.

**Powder application problems.** One of the most basic problems with electrostatic powder spray is that the powder recirculating system creates a negative pressure in the booth (unlike the positive pressure of a wet booth). This allows plant air contaminants to be drawn into the booth and into the powder collection system. To prevent this contamination requires a clean room atmosphere.

Another problem related to air movement is that electrostatic powder spray must use a gentle stream of air to deliver the powder out of the gun. An excessive air flow would tend to blow the electrostatically attracted powder off the parts. Similarly, when electrostatic powder guns are reciprocated, the reciprocating speed must be slow to prevent creating turbulence in the powder cloud.

The required gentle spray from an electrostatic powder gun presents yet another problem: an enhanced Faraday cage effect. The air pressure cannot be stepped up to force the charged powder into a confined area. The enhanced Faraday cage phenomenon increases the tendency for powder to deposit at the confined area entry and not within the area, causing wide differences in powder film thickness in these regions.

Powder coating application has other film thickness problems that relate to the basic size of the powder particles. This makes thin films below 1.0 to 1.5 mils difficult to achieve. With wet systems it is not particularly difficult to achieve films
0.5 mil thick. With the proper powder, careful application and precise conveyor hanging techniques, it may be possible to apply low film thicknesses satisfactorily.

Extremely thick powder coating films can be produced with one pass, but not everyone wants thick coatings. Powder’s tendency to yield thick films can be considered an advantage or disadvantage, depending on whether or not the thick coating is desired.

Another problem with powder coating application is the formation of clumps of powder that can be ejected from the spray gun, causing paint film blemishes and rejects. One cause of clumps is impact fusion, which is the frictional heating and partial melting of powder moving through the circulation system. Impact fusion tends to occur when fast-moving powder collides with a surface, such as when a powder flow makes an abrupt right turn, sending particles “crashing” into a wall. Good powder circulation design avoids such sharp turns. Powder clumping can also be caused by wet or moist powder, powder being stored in areas warmer than the recommended 75 to 85°F and powder stored beyond its shelf life.

The difficulty in changing powder coating colors is another application disadvantage. All areas of a system that contact powder must be cleaned thoroughly of all traces of a powder before a new powder is put into the system. Changing colors with powder tends to be labor-intensive.

The absence of solvent makes it difficult for some powder resins to achieve adequate flowout. For this reason the part should be heated rapidly so the powder melts and flows before cross-linking occurs. Additional heating will cause the curing of the coating. This restricted flow tends to cause orange peel and a low distinctness of image. Fine grinding of the powder is costly, but in some formulations this can help reduce the visual effects of restricted resin flow rheology.

Powder’s requirement to be stored in a cool, dry place can be considered a disadvantage because it adds to capital investment. Powder needs to be kept cool to prevent possible premature cross-linking. It must be kept dry to prevent clump formation. Powder storage areas should be air-conditioned to maintain cool temperatures and low relative humidity.

**Powder coating repairs.** Repairing blemishes in powder coating films can be a difficult process. If the defective product is put back on the line and powder coated again, the coating can become thick and brittle. If this happens, the part will need to be stripped and recoated. A considerable difference among powders is found in their ability to produce a smooth appearance when recoated with powder. Intercoat adhesion of recoated powder coatings also varies widely.

Defective areas on powder coated surfaces can often be recoated with liquid coatings. However, formulating a liquid coating to match a deposited powder coating can be difficult. Some companies or consumers have rejected the potential use of powder coating because no liquid repair paint could be found that would exactly match the color, gloss and texture of the powder coating. For example, the
State of New York will not purchase highway lighting poles that are powder coated for this reason.

Powder coating's unique properties make it troublesome to strip with conventional caustic or cold solvent materials. The most common way of removing powder coatings from hooks and hangers is by burnoff in high-temperature ovens. This works well providing that the temper of the steel in the hooks and hangers is not adversely affected. Stripping parts for repainting may present similar difficulties.
Chapter 15

Conveyors for Painting

Industrial painting is done either by the batch processing or with a conveyor. In the typical batch processing, relatively small quantities of products to be painted are moved manually from station to station and handled manually at each station. A short monorail conveyor with manually moved parts can be used for low volumes of large heavy items.

When large quantities of parts are to be painted, the work is moved automatically along the paint line by a power conveyor. Paint line conveyors all have as their object to move parts to specific destinations. They can be categorized into the following general types:

- Flat conveyors
- Chain-on-edge conveyors
- Chain-in-floor conveyors
- Overhead chain and trolley conveyors
- Inverted conveyors

**Flat conveyors.** A flat conveyor is probably the earliest type of paint line conveyor. A motor driven belt-like device carries parts along a pathway, allowing various finishing steps to be performed. This method is used for finishing single sides of flat stock, such as doors, partitions, and wood paneling, using spray roll, or curtain coating. The conveyor may be of various widths and lengths, depending on the size of the product being finished.

The parts can also be removed by hand from the conveyor and taken to a nearby finishing station and then returned to the conveyor. The main advantage is simplicity. The main disadvantages are generally a low product weight limitation and the requirement to have operators remove parts for processing and then return them to the conveyor.

The term “flat conveyor” can include a number of conveyors of this general type, such as polyurethane belt, wire mesh, dual chain with cradles, cross slat, pin, perlon filament and flatbed.

**Chain-on-edge conveyors.** Chain-on-edge conveyors consist of a small conveyor chain equipped with vertically mounted spindles to carry parts to be painted, as
shown in Figure 15-1. These conveyors are used in disk, bell, and spray-painting and to transport the parts through an oven. Chain-on-edge conveyors can be arranged in either a horizontal continuous loop configuration or in an “over-and-under” vertical loop arrangement. In the continuous loop, all of the spindles are upright at all times. In the over-and-under configuration, half of the time the spindles are inverted. The over-and-under could be likened to a belt conveyor with spindles.

The spindles passing in front of the application device usually are made to rotate for consistent paint coverage. Each spindle is equipped with a sprocket (pinion) that engages a rack near the spray guns, forcing the spindle to rotate. Their main advantage is simplicity and high efficiency. Their chief limitation is that only painting and baking can be achieved, they are not suitable for use in pretreatment operations.

Chain-in-floor conveyors. A chain-in-floor conveyor consists of a driven chain embedded in a channel slightly below the level of the plant floor. The conveyor’s function is to pull large wheeled items, or trolleys bearing parts. The chain is full-size and can pull heavy loads. This type of conveyor is often used in furniture plants to pull agricultural or earth moving machinery, and large pieces of furniture through various spray painting and sanding stations. The conveyor’s main advantage is simplicity. Its basic disadvantage is its restriction to wheeled carriers or items having their own wheels.
Overhead conveyors. The overhead conveyor consists of a driven steel cable or chain to which trolley-wheel hooks are attached at regularly spaced intervals. The chain or cable is supported by trolleys that ride on a continuous track supporting I-beam. Figures 15-2A, 15-2B and 15-2C show examples of the most common types. The overhead chain-and-trolley conveyor is the workhorse of the finishing industry. It can carry large volumes of parts through all finishing steps: sanding, washing, drying, painting and baking.

The overhead trolley conveyor may be “open” or “enclosed.” The enclosed type has a box enclosure around the top, sides and bottom, except for a slit running the length of the bottom for hanger passage. The cable type trolley conveyor always uses an open I-beam support.

Overhead conveyors are driven by electric motors with gear boxes and sprockets. A “take-up” station allows tightening the slack on the conveyor from time to time as the cable stretches or the chain components wear. These conveyors are usually equipped with automatic oilers that periodically spray lubricant on the trolley wheel bearings.

Figure 15-2. Three Examples (A, B and C) of Overhead Conveyors
The conveyors generally have automatic brush-type cleaning equipment that runs continuously to keep the chain and trolleys clean. It is vitally important in electrostatic painting to have a clean I-beam surface (on which the trolley wheels ride) and clean trolley wheels to complete the electrical circuit to ground. Without continuous cleaning, the I-beam riding surface and wheels tend to collect dust and dirt and lose their good electrical ground.

Overhead conveyors should be protected in spray washers, spray booths and ovens. A conveyor running unprotected inside a spray washer will be saturated continuously with cleaner, phosphate and sealer rinse solutions, which will wash away lubricant and bring quick failure to wheel bearings. An unprotected conveyor inside a spray booth can collect exorbitant amounts of overspray, fouling the trolleys and chain and eliminating a good electrical ground. The conveyor inside an oven may have the lubricant driven out by heat. Sometimes an overhead conveyor runs above a washer; a slit in the roof of the washer allows hangers to pass. Plastic brushes close the slit gap minimize washer moisture escape. One type of conveyor is run inside the washer in a shroud device. A steady flow of air into the shroud maintains a positive pressure to prevent moisture from reaching the conveyor. The same type of shroud can also protect a conveyor in a spray booth and in an oven.

Overhead trolley conveyors can be operated at a wide speed range. The top speed is limited by the slowest station on the paint line. For example, if a part must be in a 24-foot spray booth for 3 minutes, the top conveyor speed would be 24 feet divided by 3 minutes, or 8 feet per minute.

Overhead conveyors can be tied in with power-and-free conveyors. The power-and-free feature allows separate trolleys with hangers to be alternately pushed by “dogs” on the conveyor. The dogs are fixtures that can be made to extend or retract to move the trolleys to various stations for desired time intervals. Power-and-free conveyors allow individual hooks to be disengaged from the conveyor line for accumulating parts, such as in an oven for longer dwell times, or for multiple routing of a variety of parts requiring non-uniform processing.

The overhead conveyors can also be linked with various transfer stations that allow one conveyor loop to pass parts to another conveyor loop. The conveyor can also be used with elevators to lower and raise parts for various processes such as pretreatment baths, electrocoating solutions and batch-type ovens.

About the only disadvantage of an overhead conveyor is that it tends to collect dust and dirt, which can fall onto parts being finished. Figure 15-3 shows car bodies being moved through a spray booth by an overhead conveyor equipped with coverings to prevent conveyor dirt from falling onto the painted bodies.

**Inverted conveyors.** These conveyors are “flipped-over” versions of overhead conveyors riding at floor level or slightly above floor level. They are equipped with regularly spaced mounting devices. They are often used to transport parts for which dirt-free finishes are critical, especially those that will be clearcoated, such as car bodies or outboard motor covers, through spray booths and ovens. A major
advantage of this type of conveyor is that the conveyor mechanism—which tends to collect dirt—is below the part being finished, thus eliminating dirt from falling onto parts. Another disadvantage of inverted conveyors is that they restrict access inside the plant. Personnel can usually walk under an overhead conveyor line but an inverted conveyor mounted above the floor is difficult to cross; personnel may be forced to walk around rather than over the inverted conveyor line. Inverted conveyor loops are used alone and in concert with overhead conveyor loops and power-and-free systems.

Modern finishing systems feature advanced automation, which is made possible by conveyors and computerized control. Each paint line conveyor system is custom-designed for a particular product. The conveyor system is required to move products through each finishing station. Banks of products may need to accumulate at various locations. The conveyor needs to be at the proper height above the floor for part loading and unloading. Proper conveyor design, continuous brush cleaners and automatic lubrication systems will ensure long conveyor life with minimal maintenance. Conversely, poor conveyor design, inadequate conveyor cleaning and improper lubrication guarantee short conveyor life and serious maintenance problems.
Chapter 16

Finishing Robots

The term “robot” often conjures up an image of a manlike mechanical device that can walk (in zombie fashion), talk (always in a monotone) and do various simple tasks (such as bringing its master a cold beer on a hot day). This image probably is the result of various Hollywood movies and television situation comedies over the years. Such a device has little value in the industrial world.

Industrial robots have hardly any resemblance to their Hollywood cousins. They don’t walk or talk, and rather than do various tasks, they are designed for specific, repetitive jobs.

An industrial robot is a device mounted to the floor, wall or ceiling and is capable of moving about various axes to perform specified functions. It usually will contain an arm that mechanically resembles a human arm with a wrist and gripping capability. It likely will have a control center and an electronic memory so that it can repeat preprogrammed instructions.

The robot arm can be designed to have movement along (or about) three axes:
- Translation—an axis along a horizontal base
- Elevation—a vertical axis perpendicular to the base
- Reach—a horizontal axis perpendicular both to the base and to the vertical axis

The wrist part of the arm can be designed to have movement along (or about) three additional axes:
- Yaw—angular right and left
- Pitch—angular up and down
- Roll—angular around

Three additional axes of motion can be achieved by moving the entire robot as follows:
- Parallel to conveyor travel (to track a moving target)
- Perpendicular to conveyor travel (to move toward and away from the conveyor)
A robot with full arm, wrist and base motions would therefore have nine axes of motion.

The electronics to control a robot's motions can be programmed "point-to-point" or "continuous-path." Point-to-point programming moves a robot in a series of straight lines that connect a series of points widely separated in space, which requires only a limited memory. Point-to-point programming is for intricate movement and extensive control.

Continuous path programming is like point-to-point but with a major difference. In continuous path programming, the movements are between points that are very close together. Constant feedback allows the motion to follow the series of points to simulate moving along a continuous curve. Continuous path programming requires extensive memory and computing capacity. This type of programming is useful where intricate contoured paths need to be followed, such as in spray painting parts with complex shapes.

Robotic motion is usually achieved with "servo" control for each axis. A servo is an electrical/mechanical device that provides an output motion according to a given input signal. When equipped with electrical feedback circuits, a servo's output motion can be continuously monitored and adjusted (corrected).

Robots are powered either directly through an electric motor or indirectly through a hydraulic or pneumatic motor.

- Electric robots tend to be highly accurate and carry light-to-medium payloads
- Hydraulic robots are characterized by an ability to "give" when under stress and typically carry heavy-to-medium payloads
- Pneumatic robots are often used in fast-velocity applications with light payloads

Industrial robots are categorized according to their design function. The categories include assembly, material handling, welding and spray painting. Assembly robots are programmed to perform one or more tasks on an assembly line. Material-handling robots are programmed to move various products from one location to another. Welding robots are programmed for use in automatic welding applications. Spray-painting robots are almost always programmed to manipulate a spray gun through a series of motions to paint products either stationary or being moved by a conveyor.

The four categories of robots are very similar in appearance and design. With minor modification, most robots could operate in any category. Material-handling robots vary in size according to the weight of the product being handled. A material-handling robot in a laboratory would likely be bench-mounted and be very small, perhaps with an arm a foot long. A material-handling robot operating in a foundry to move heavy castings would be very large and be designed with a large, sturdy arm capable of lifting the heavy parts, or on a gantry.
About 35% of industrial robots are used for assembly, 35% for material handling, 20% for welding and 10% for spray painting. Applying paint robotically with a rotary bell is being done on a limited basis.

**Spray Painting Robots**

Devices that operate in paint spray booths either must not generate sparks or if they do, the sparks must be enclosed in a fail-safe system to prevent the possibility of the spark igniting flammable material in the booth (such as solvent). Early-model spray-painting robots were hydraulic-powered and spark-free, preventing the possibility of igniting a flammable atmosphere.

However, it wasn't too many years before electric-powered spray-painting robots were put into service. Electric systems are subject to the possibility of generating sparks. A fail-safe system was devised to prevent the possibility of sparks. All potential spark-generating equipment is housed in an enclosed compartment that is filled with a nonflammable gas at a positive pressure, preventing entry of flammable solvent fumes. If the compartment should lose its positive pressure, the electric power becomes inoperative.

Electric spray-painting robots became popular because of the elimination of potential hydraulic leaks and because the electric robot is a modular package. A hydraulic robot needs a separate source of hydraulic power. The increased accuracy capability of electric-powered robots isn't much of an advantage in spray painting, which doesn't require critical accuracy. A hydraulic powered robot's capability to handle large payloads is usually no advantage in spray painting, where a spray gun payload may weigh only several pounds.

The number of axes required in a spray-painting robot depends on the product being painted. A simple product such as a flat object (nonconveyorized) could perhaps get by with a spray-painting robot with only three axes. A complex object such as a conveyorized car body could require a spray painting robot with all nine axes. The robot package itself could have six axes. The axis to track the moving car body would be the seventh axis; a capability to have the entire robot move to and away from the car body would be the eighth axis; a capability for the entire robot to be raised and lowered would be the ninth axis. Figure 16-1 shows a robot painting the inside of a station wagon.

Spray-painting robots are programmed usually in combinations of point-to-point and continuous-path, depending on the shape and size complexity of the product being painted. A growing tendency is to program a spray-painting robot “off line.” In this technique an operator in a remote location (off line) equipped with a computer and appropriate software can program the robot. Off-line programming can be used in combination with conventional teach systems where a robot is programmed by an operator moving a teach pendant through the desired spray
Figure 16-1. Robot Replaces Manual Spraying Prohibited by OSHA On Enclosed Van Interiors

Figure 16-2. Operator Teaching Robot Desired Spray Motions
Spray-painting robotic programs need to be synchronized with conveyor loading and conveyor speeds. The programs also need to include start-stop functions and color-change operations.

Because a robot cannot see, parts need to be hung on a conveyor the same way every time. No variation in the alignment of the hanging parts is permitted. Crooked paint hooks and hangers, and parts that are swaying or swinging as they move past the robot may drift outside the programmed path of the robot, resulting in poorly painted products. Double-point hanging is often used with robotic painting to secure the parts and reduce the likelihood of sway or misalignment of parts on the conveyor line, as shown in Figure 16-4.
Machine “vision” can be used with spray-painting robots. In machine vision, video cameras record the shape of the parts on the conveyor approaching the spray booth. If a shape-change is observed, the computerized vision control center can recognize the new shape and instruct the robot’s computer control center to shift spray-painting programs accordingly. Machine vision systems tend to be expensive; the same result can usually be obtained with photocell detectors, which have been triggering spray-painting systems for years.

Some spray-painting machine vision systems aim a video camera at a specific area on a product to be coated. If the camera position-detection system observes that the part is positioned slightly askew, it can alert the robot control center, which can shift the robot’s program to compensate for the off-positioned part. This type of system is being used in automotive sealer applications, where a bead of sealant is applied automatically to cover corrosion-prone seam-weld areas.

Spray-painting machine vision applications tend to be relatively simple in scope, being limited to shape recognition and location misalignment. Full-bloom vision systems that could replicate human eyesight and brain function are a long ways down the road, so to speak.

Before installing a spray-painting robot, a great deal of planning must be done. A study should be undertaken about the feasibility of having a robot. Payback time is the critical economic point to consider. If the payback time meets a company’s guidelines, and approval is given to purchase the robot, the next step is to plan for its installation.
The space requirements for a spray-painting robot tend to be more demanding than for a human. Most spray-painting robots are larger than humans and have a much bigger work envelope. The robot will have to be housed in a spray booth to confine overspray and VOC. The robot’s physical reach must not exceed the constraints of the booth.

A spray-painting robot requires considerable peripheral equipment. An off-line teaching booth in close proximity to the paint line for the preparation of new spray painting programs, will eliminate the need to interrupt production runs to perform teaching operations.

The large mass of the robot will require an overhead lifting device to relocate the robot or to move it for repairs. Easy access must be provided for servicing electrical and hydraulic components.

For ease in maintaining a spray-painting robot, the equipment should be designed to include:

- a computer with self-diagnostics
- interface electronics with only one printed circuit board per axis of motion
- precalibrated board backups for each drive axis
- easy calibration procedures

To protect people working nearby from being struck by the robot, restraining guard rails, gates, fences or other protective devices must be installed. A number of other important safety measures are needed to protect people and equipment in the area.

In case of malfunction, runaway protection is needed so that an out-of-control robot does not cause injury. A warning bell or light can alert employees to this condition. Alarms for runaway robot conditions should be loud enough to be heard readily above plant noise. Fail-safe brakes are necessary on robot arms to prevent wild movement in the event of a hydraulic or electrical failure. Emergency shut-off switches must be located for high visibility and quick access.

Pressure-relief valves are needed in the hydraulic system to prevent overload of the pump and motor. A velocity “fuse” in each hydraulic supply line can prevent high flow rates. Software limits to ensure safe stoppage of the robot arm in all major axes should be backed up with electrical limit switches and mechanical shock absorbers. Robot arms can be nylon-covered to preclude any sparking in the event of a collision with a metallic object.

**Spray-Painting Robot Advantages**

The advantages of spray-painting robots can be categorized into two areas:

- cost reductions
- quality improvements

**Cost reductions.** The most obvious cost reduction involves labor. A typical robot
installation will displace one to three painters. If the robot is used on more than one shift a day, the savings are multiplied. A robot’s speed capability is the reason why it can often replace several painters. The robot arm can simply move faster than a human arm—and without tiring. Robots can paint in hazardous environments that would be unsafe for an operator. They can be used for painting operations that are uncomfortable or of marginal safety. Robots are suitable to apply dirty, malodorous materials and to work in hot, humid or other unpleasant environments. Robots can also perform physically demanding contortions and mechanical manipulations that would prove unendurable to a human operator if done for any length of time. Long reaches that require an extension or pole-gun for a manual sprayer can be accomplished easily with a robot. Robots are being used to spray with absolute safety many two-component polyurethane paints that have a toxic isocyanate component.

Another cost reduction that can be substantial involves paint savings. The average replacement of a semiautomatic system by a robot will reduce paint consumption by 15 to 20%. This savings accrues from repetitive and accurate painting motions, finely tuned gun triggering and multiaxis movement that can closely follow part contours. The actual material savings will depend on the volume of production, the shape of the parts and the type of paint applied.

An important savings is in energy. Because no human operators need be present in a robot-equipped spray booth, the amount of air exhausted from the booth can be reduced. This can result in a considerable energy savings, especially in cold climates during winter months when makeup air needs to be heated. Ventilation cost is reduced nearly 50% for robotic spraying compared with manual operations.

**Quality improvements.** Robots provide absolute part-to-part uniformity of coating. This improves quality and reduces or eliminates rework and rejects (or possible field recalls on products). Some plants that switched to spray-painting robots have reported a 75% reduction in rejects. The most capable painter can be selected to “teach” the robot, repeating as many times as is necessary to get the absolute best spray movements and most precise gun triggering.

A fringe benefit associated with robotic spray painting is that paint savings translate into reduced VOC emissions. Paint that is not sprayed will not emit VOC. Lowered VOC emissions are being required almost universally. Any finishing system that reduces VOC emissions will help a company retain its operating permit from its jurisdictional regulatory agency.

**Case History**

The following case history describes how a company saved a large amount of money by switching to spray-painting robots. The plant was manually spraying plastic auto parts on two separate conveyor lines. To meet production, it had been
necessary to paint reworked parts on overtime. One line was altered so that all painting was done by four robots and four stationary electrostatic guns. The second line was left unchanged and used just for spraying repair parts; it operated on straight time only. The change allowed eight sprayers per shift to be reassigned. Three gun technicians were added. The net reduction of 13 positions resulted in an annual savings of over $500,000. The savings of an hour a day overtime per operator for each shift gave an additional yearly savings of over $333,000. The annual paint savings was also estimated to be $333,000. Although no exact dollar value can be assigned to these factors, VOC emissions were reduced and paint finish quality was improved by robotic application. The total implementation cost was slightly over $1 million, but the annual savings was close to $1.25 million.

Spray-Painting Robot Costs

Although the advantages of spray-painting robots include cost reductions and quality improvements, these devices tend to be costly. A spray-painting robot cost will vary considerably, depending on its size and performance capability. A low-requirement unit may cost in the low “five figures.” A high-performance spray-painting robot may cost in the low to mid “six figures.”

Added costs include robot installation and training for personnel to learn to operate and maintain the device properly. In addition, all paint shop personnel must be trained in general safety precautions associated with the robot. The average robot requires an annual maintenance expenditure of roughly $4000, including end-of-shift cleanup and periodic preventive maintenance.

A formula to determine a robot payback can be expressed as follows:

\[ Y = \frac{R_C}{W_s + P_s + R_d - (M_c + S_c)} \]

- \( Y \) = years payback
- \( R_c \) = total robot purchase and installation costs
- \( W_s \) = replaced worker salary for a year
- \( P_s \) = production savings for a year (paint savings, energy savings, etc.)
- \( R_d \) = robot depreciation for a year
- \( M_c \) = maintenance costs for a year
- \( S_c \) = staffing costs for robot for a year
In a hypothetical case, suppose that
\[ R_C = \$100,000 \]
\[ W_s = \$ 30,000 \]
\[ P_s = \$ 25,000 \]
\[ R_d = \$ 25,000 \]
\[ M_c = \$ 10,000 \]
\[ S_c = \$ 20,000 \]

Then,

\[
Y = \frac{\$100,000}{\$30,000 + \$25,000 + \$25,000 - (\$10,000 + \$20,000)} \]

\[ Y = \frac{\$100,000}{\$50,000} = 2 \text{ years payback} \]

**Future Developments**

Spray-painting robotic research and development will likely focus on the following areas:

- Sensing devices
- Painting speed
- Precision of operation
- Repeatability
- Minicomputer controls
- Voice command recognition
- Artificial intelligence

Improved sensing devices could increase the efficiency of color changes, improve product identification, detect and correct misaligned parts and identify/select parts from mixed products. Precise machine vision is available now but costs are prohibitively high. Increased painting speed could reduce robot costs and thus lower payback time. Improved precision of operation and repeatability would increase quality.

Minicomputer controls, voice command recognition and artificial intelligence are steps toward making the spray-painting robot have the capability of the human brain.
Spray booths for powder coating were described in Chapter 14. This chapter will deal with spray booths for liquid painting. Spray booths for powder coating and spray booths for liquid painting, while similar in concept to serve as an enclosure for depositing a coating, are totally different in design.

A spray booth (for liquid painting) can be defined as an enclosure equipped with a means of safely capturing overspray paint, diluting and exhausting solvent vapors and replacing the exhausted air with clean makeup air. Makeup air may be supplied inside the booth by fans and ducts, or plant air may be allowed to replace air exhausted from the spray booth. This definition makes a spray booth sound exceedingly simple. Actually, a spray booth is quite a complex system.

A spray booth almost always has openings on both side walls for entry and exit access for conveyed products to be painted. A spray booth without such conveyor openings is sometimes used for low-production batch spraying. Access for product entry and exit is through the wall at the front of the spray booth. The front wall may be fitted with doors.

The need for forced air exhaust and forced air makeup in a spray booth presents an engineering problem. The exhaust must be sufficient to satisfy health and insurance underwriter regulations. Exhaust requirements are greater when humans are in the booth. Air makeup must do two things: replace the exhausted air and supply a slight amount of additional air to maintain a positive pressure, which is necessary to prevent drawing plant air into the booth. The extra amount of air makeup cannot be excessive or some overspray could possibly be forced out of the conveyor openings into the plant instead of into the exhaust system.

Makeup air is drawn into the booth from outside the plant to avoid disturbing the rest of the plant’s air balance. If the spray booth air were taken from inside the plant, a negative plant pressure would be created. Plants like to maintain a slight positive pressure to avoid drawing unfiltered and unheated air into the plant. The booth makeup air is filtered to introduce clean air into the booth. In northern
climates the air makeup is heated and often humidified during cold weather. During summer temperature extremes, it may be air-conditioned. Adjusting the temperature of the makeup air requires a great deal of energy and so is rarely done.

Sometimes moisture is introduced into dry makeup air to prevent excessively fast evaporation of volatiles from the applied paint film. This extra moisture is needed only in frigid weather because very cold air used for makeup in the spray booth holds just a tiny amount of moisture. The amount of water vapor in the air has a significant effect on the rate at which paint solvents (and water) evaporate from wet paint films.

If the primary movement of air makeup and exhaust is from the booth ceiling to the floor, the booth is termed “downdraft.” Figure 17-1 shows a downdraft booth; fresh makeup air enters through the filters at the ceiling, and overspray is exhausted through the floor grating to a filtering system. If the air movement is mainly horizontal, the booth is termed “sidedraft.” In both types the air movement permits a human spray operator to work in a safe environment without a separate fresh-air supply for breathing. However, where toxic chemicals are sprayed, a separate fresh air supply needs to be supplied for human breathing, usually to a hood that fits around the operator’s head. In automated booths where humans are not working, the air flow rates may be reduced.

The overspray paint cannot be exhausted directly from a spray booth to outside a plant because of exhaust ductwork fire hazards and the possibility of painting

![Figure 17-1. Downdraft Spray Booth](image-url)
cars and buildings in the vicinity of the exhaust outlet. Unfiltered spray booth exhaust sends overspray paint into the exhaust ductwork and onto fan blades, causing a fire hazard. The overspray paint accumulation can unbalance fan blades, causing fan vibration and wear and possible damage to the exhaust housing. Overspray paint exhausting directly to outside the plant can accumulate on nearby buildings and cars, causing untold damage. Insurance claims are filed annually in North America for the accidental painting of cars in the vicinity of a plant with poor spray booth exhaust filtration.

The method of filtering the paint overspray from the exhaust is another way of categorizing spray booths. If the overspray is removed by filters, it is termed a “dry-filter booth.” If the overspray is removed by a water system, it is called a “water-wash booth” or “wet” booth.

Before describing dry-filter and water-wash booths, a discussion is necessary on the nature of paint overspray. Atomized paint exiting a spray gun consists of various sizes of paint droplets in flight toward and past the vicinity of the part to be painted. As the droplets move through the air, solvent evaporates from them continuously, creating solvent and particulate (resin, pigments and additives) components in the overspray. The evaporated solvent, both from atomized particles and from the deposited paint film, is comprised of extremely tiny molecules and almost totally escapes filtration, moving directly into the exhaust air stream. The remaining overspray paint particulate missing the target are carried in the air exhaust stream, but are mostly captured by a filtering device before they leave the booth.

**Dry-Filter Booth**

In a dry-filter booth the overspray (evaporated solvent molecules and atomized paint particulates) are drawn by air circulation through a network of air filters into the exhaust duct system. Nearly all dry-filter booths are sidedraft: Air enters the booth from behind the spray guns and exits the booth through the filters into the exhaust plenum. Figure 17-2 shows a side draft dry-filter booth. Variations of the sidedraft are possible. Clean, filtered air can enter the booth through a ceiling plenum and descend behind the spray guns and parts to be painted, through filters on the back wall and out the exhaust stack. It is much preferred, however, that air flow into and out of the booths be totally linear since it is far more efficient and clean.

Dry-filter booths use easily replaceable disposable filters that vary in size, composition and particulate capture efficiency. The filters may be of the strainer type or the baffle type. The baffle type can take heavy loading levels but is not highly efficient at removing all of the overspray particulates. The strainer type is effective at removing most particles, but tends to “blind” (clog) quickly. For some time, manufacturers have been making variable-density filters or dual-material
filters. These avoid the heavy face loading of the strainer type but can still achieve high capture efficiencies. A baffle-type filter is often placed ahead of a strainer type to combine the advantages of both.

When filters load up with paint to the point that air flow is impaired, they must be replaced. Disposal of the spent filters is usually straightforward when no toxic substances are present in the paint. The exceptions are paints that can ignite spontaneously when the used filters are stacked together. Stacking does not permit the escape of heat generated by oxygen reacting with the finely divided organic materials on the dirty filters, and spontaneous combustion can result. When this problem is encountered, the filters should be plunged into a drum of water and the filled drums then tightly sealed. Some plants must bake used filters before they are allowed to discard them in conventional ways. Baking expels residual solvents from the trapped overspray on the filters.

Getting rid of filters containing toxic paint can be expensive. Depending on the applicable regulations, used filters laden with toxic paint components, such as chromates, may need to be disposed in facilities licensed to handle toxic wastes. Somewhat surprisingly, in at least three states, if water leach tests show that only low amounts of toxics are released, then filters do not require handling and
disposal as toxic waste. Most states do not allow materials classified as toxic to be discarded so casually.

## Water-Wash Booths

In water-wash booths the overspray is exhausted through a curtain of water or overlapping pressurized sprays of water that entrap and remove the atomized paint overspray. Water curtains or pressurized sprays are usually located on the side of the booth behind the parts being painted. Some booths have the water-impingement system located below floor grating. Water-wash booths can be of either sidedraft or downdraft design. Figure 17-3 shows a sidedraft water-wash booth. Figure 17-4 shows a downdraft water-wash booth.

The water curtain or spray is pumped from a water reservoir tank and returned to the tank. The volume of the reservoir tank depends on the size of the spray booth and may range from several hundred gallons for a small booth to thousands of gallons for a very large booth. A number of booths may use a common reservoir of recirculating booth water, frequently a large “pit” tank.

If the collected overspray paint particles in the water circulation system were not chemically treated, they would stick to the sides of the reservoir and clog pumps, headers and nozzles. The chemicals added to prevent this are called...
detackifying agents. The detackifying process is called “killing” the paint.

Chemicals can be used either to float the detackified paint for skimming or to degrade it to a fine sand-like consistency that will sink to the bottom of the reservoir. To “kill” the paint, detackification agents may combine one or more of the following methods:

- Use absorbent materials such as clay.
- Use alkaline materials that chemically degrade many paint resins. High alkalinity can “sink” the sludge; lesser amounts float the killed paint, which permits removal by skimming.
- Use polyelectrolyte materials that chemically encapsulate the paint particles, rendering them nonsticky.

Detackifier formulations are available in solid form or as concentrated liquids. Best results in separating the killed paint from the water are obtained when paint particles are agglomerated by coagulants into large particles, which facilitates floating and settling.

Antifoamers or defoamers may be added to prevent foaming onto the booth floor, pump cavitation (pumping air) and impeller erosion. Foam interferes with the paint/water separation, delaying paint settling and producing excessively wet sludge, making disposal costly because of the extra handling weight and transportation expenses. Additional environmental restrictions may also apply.

Water containing organic material can be potential food for fungi and bacteria unless antimicrobial agents are used. These prevent slime, odors and corrosion pitting. To minimize these problems, the water is kept mildly alkaline at a pH of about 7.5 to 9.0.

Some paints are easy to kill; others are not. High-solids paints tend to be difficult to detackify. The detackified paint sludge can be collected by skimming floating material, by scraping up sunken material or by filtering. Any toxic materials remaining in the booth water after sludge removal must be eliminated before releasing the water to drain.

Disposal of wet paint sludge has become an increasingly expensive problem, especially if toxic components are present. In light of so many health hazards being traceable to chemicals that were improperly disposed of, many areas are exceedingly reluctant to allow dumping of any manufacturing wastes in their communities, much less their burial or incineration. Many regions either have laws or are considering laws to ban hazardous chemicals disposal except on the plant site, and then only by approved methods.

Some efforts have been made to recycle paint sludge, but it is usually less costly simply to dispose of it and buy new paint. If no toxics are present, sludge can be pressed into briquettes and burned for their heat value. Pressing to remove water is necessary because wet sludge burns poorly and may require almost as much heat to evaporate the water as heat generated by combustion. At least one company makes equipment to heat and dry paint sludge and then crush it to a free-flowing powder.
Spray Booths for Liquid Painting

High-Solids Overspray Recovery

Recovering and recycling high-solids overspray is increasing in popularity. High-solids overspray remains tacky or sticky because of the absence of cross-linking and due to the low amount of solvent that can evaporate. This trait makes recovery and recycling fairly simple.

Vertical baffles are stacked behind the parts being painted in a side-draft booth. A large portion of the overspray is drawn toward the flat overlapping or spiral-channeled baffles, collecting on them and gradually flowing downward into a trough. The trough slopes into a collection container, recovering much of the overspray paint that would have been caught up either by dry filters or by water-wash systems. Augers are also used to move the collected overspray.

The collected paint needs to be filtered and adjusted to viscosity (by solvent addition) before it can be reused. Occasionally a slight color correction may be required.

High-solids overspray recovery produces great cost reductions by allowing paint purchasing to be reduced and by lowering dry filter replacement or sludge-treatment requirements.

Low-solids solventborne paint overspray cannot be recovered because it dries so quickly. The same type of problem exists with recovering waterborne coating overspray.

Dry-Filter or Water-Wash Booths?

Whether to install a dry-filter or water-wash booth depends largely on the amount of painting to be done. Equipment and operational costs of a dry-filter booth tend to be lower than for a water-wash booth until at least 75 to 100 gallons of paint are applied each day. Having to stop painting to replace filters more than 2 or 3 times per shift can be avoided by switching to a wet type spray booth. The particular paint being sprayed has an effect on the relative costs between wet or dry capture as well. How readily the paint is chemically detackified, the cost to dispose of wet sludge and the method of paint application are also important factors in booth selection.

VOC Removal

Because VOC readily escapes through dry filters and water-wash booths, VOC emission regulations for industrial painting are structured to require low-VOC coatings to be used. For example, a category of finishing (automotive, appliance, etc.) may require that coatings contain no more than 3.5 pounds of VOC per
gallon. As long as this requirement is met, the VOC given off during coating application is within compliance. However, the regulations require that if coatings are used that exceed the VOC maximum, “add-on” VOC treatment methods must be used, such as incineration or carbon adsorption.

In the incineration of VOC, the fumes are burned at about 1400°F to convert the VOC to carbon dioxide and water vapor. The incineration process is inherently energy-inefficient unless the hot exhaust can be used elsewhere in the finishing line or in the plant. Often the exhaust is passed through heat exchangers to preheat air makeup for ovens and other burners and to provide heat for dry-off ovens and for washer baths. Attempts are made to get the incinerator exhaust temperature as low as possible before it leaves the plant.

Incinerators are used extensively on coil coating lines, where low-solids coatings are often used and where the VOC emissions from coatings application and bake ovens are high. The VOC concentration often is high enough to serve as fuel for the incinerator, allowing a cutback in natural gas use. Incinerator use on coil coating lines is very cost-efficient.

Incinerator use is impractical where VOC emissions are low. As a general rule of thumb, incinerator use is limited to destroying VOC from bake ovens where fume concentration is fairly high and where the VOC temperature is already raised 300°F or so above ambient, requiring that much less heat input to reach incinerating temperature (approximately 1200°F). Incineration use is impractical except in a few special instances as a means of destroying VOC from a spray booth because the high air makeup and exhaust requirements for spray booths provide an excessive amount of diluted VOC air to handle. Finishers with modest production loads should comply with the VOC pounds/gallon coating limit and not consider incineration.

Activated carbon-bed adsorption units, while totally effective in cleaning solvent vapors from booth exhaust air, tend to be prohibitively expensive except for large painting operations. Huge beds of carbon are needed, plus facilities for periodically stripping solvent-saturated carbon beds with a flushing material. In most cases live steam is used for regenerating the carbon. Equipment to separate solvents from the condensed mixture of steam and solvents adds to the high cost of adsorption systems. Several newer designs continuously strip and concentrate the booth air/solvent stream ahead of incineration. A rotating carbon-fiber wheel cleans the exhaust air of all solvents. Part of the hot incineration exhaust back-flushes the adsorbed solvents off the carbon wheel and concentrates them by a factor of 5- to 20-fold. The smaller, richer solvent and air mixture can be incinerated less expensively.
Chapter 18

Painting Plastics

“Plastic” is the generic name for a broad category of materials molded from petroleum-based organic polymeric resins that may contain various additives to produce certain properties and pigments to yield particular colors. Plastic products have been molded into practically every conceivable shape with an almost infinite assortment of properties to facilitate each end use.

Plastic resins are characterized by complex organic chemistry involving primarily carbon, oxygen and hydrogen atoms held together in chainlike fashion by mostly single and double chemical bonds. Resin molecules differ vastly in size, chemical makeup and degree of polymerization.

Resins are categorized typically into two types: thermoplastic and thermosetting. Thermoplastic resins are characterized by having various lengths of polymer chains that are held together by mutual attractive forces among the individual molecules. Thermoplastic resins can always be reformed into a new shape with the application of heat. Thermosetting resins consist of multiple polymer chains that have been cross-linked with chemical bonds to become to some degree permanently rigid. They cannot be reformed readily into a new shape with the application of heat. Thermosetting resins can have various types of cross-linking.

Plastic resin types include acrylic, polystyrene, polypropylene, acrylonitrile butadiene styrene (ABS), polyester, polycarbonate, nylon, polyphenylene oxide (PPO), acetal, polyvinyl, urethane, cellulose acetate butyrate, phenolic, thermoplastic olefin (TPO) and ethylene propylene diene monomer thermoplastic rubber (EPDM). There are countless others as well.

Resins have acquired other generic names that relate to how they are used. These include sheet molding compound (SMC), a thermosetting polyester resin with 25 to 32% fiberglass reinforcement; reaction injection molded urethane (RIM); reinforced reaction injection molding (RRIM) with 8 to 32% fiberglass reinforcement; IMR, which is RIM or RRIM containing internal mold release;
Plastic formulas can include single resins or blends of various resins. They can contain a host of different additives, such as fillers and plasticizers. One additive (chopped fiberglass) is used in a category of plastic called fiberglass-reinforced plastic (FRP), which may consist of various resin blends and other additives.

Why Paint Plastic?

If pigment can be added to produce formulations with molded-in color, why bother to paint plastic items? Pigment is added to numerous plastic formulations for various products. A good example is the modern telephone, which is available in various molded-in colors, but many telephones are also painted. This allows the manufacturer to stock only a few basic colors of molded phones and still be able to quickly supply any desired colors by painting stock phones. Plastic products with molded-in colors are used mostly indoors away from sunlight, which tends to fade the colorants in many plastics.

Whether to mold in the color or to paint a nonpigmented plastic product (or both) is a decision that needs to be made for each individual case. The governing parameters tend to be cost, appearance quality and product performance properties.

The reasons for painting plastic are many and include:
- Highlighting
- Texturing
- Protection
- Uniformity
- Hiding
- Functionality
- Improving Conductivity
- Creating a Second Surface

**Highlighting.** Selective areas of plastic products may be painted to highlight structural details. Areas may be painted in contrasting colors for decorative effects, or with identifying names, symbols and logos. Examples are the plastic wind deflectors atop truck cabs, which commonly contain company names, identifying patterns or advertising. Plastic hulls of boats frequently have glamour stripes painted in horizontal arrays. Plastic containers, both reusable and single use types, have brand names painted on for identification and to increase sales appeal.

**Texturing.** Coatings on plastic can give texture patterns or a desirable tactile character to certain areas of products. Computer keyboards are an example.

**Protection.** Many plastics are sensitive to solvent etch, crazing or mechanical abrasion. Protective coatings are applied to enhance the durability of such
products. For example, solvent damage to polycarbonate can be reduced by painting.

**Uniformity.** Gloss and textural differences are evident throughout many molded plastic parts. In addition, most molded plastic parts tend to have glossy surfaces. Painting can produce a uniform gloss across the product that can be either higher or lower than that of the original part. Toys are often painted in high-gloss colors. Plastic furniture parts usually receive low-gloss paint finishes to eliminate the unattractive appearance of glossy plastics. Wood-graining paints can give a matching pattern to items constructed of both wood and plastic.

**Hiding.** Swirls and related visual defects in reinforced plastics may need to be hidden by painting. Coatings can give a smooth appearance when plastic parts are sanded to remove flash, parting lines or injection molding marks.

**Functional.** Many clear lenses such as those over instruments in an automobile dashboard or an airplane cockpit are painted in selected areas. Interior sections may receive a reflective paint to increase light output; exterior areas may be painted black to stop light from escaping in certain other locations of the lenses.

**Conductivity.** The low electrical conductivity of most plastics may require coatings to meet governmental guidelines for electromagnetic interference (EMI) and radio frequency interference (RFI) shielding. Safety grounding requirements may also require special electrically conductive coatings. Nickel-containing paints are often used for these purposes. Conductive paints are also used to prevent the accumulation of static charges on plastic components.

**Second surface.** “Second-surface” finishing is unique to transparent plastic parts. For example, motorcycle helmets of clear plastic are often painted on the inside of the shell with various decorative colors, such as metallic reds and blues. The paint is visible through the plastic shell, which protects the paint from scratches and abrasion. The metallic paint inside the shell is normally coated with an opaque paint to prevent light leaks and to protect the decorative coating.

### Cleaning Plastic Before Painting

Like any other surface, plastic should be thoroughly clean before painting. Most contaminant problems develop in three areas:

- Fingerprints
- Dust and lint
- Mold release

**Fingerprints.** Fingerprints (skin oils) can usually be removed satisfactorily with a simple detergent cleaning. They can be avoided altogether by requiring handlers from molding to painting to wear cotton gloves. The gloves should be changed at least daily.

**Dust and lint.** Because nearly all plastics are nonconductive, they often build up
static charges that hold lint and dust tenaciously onto surfaces to be painted. Wiping with a tack cloth in many instances will not remove all of the contaminants, which can cause visible defects in the applied paint.

One of the preferred methods of removing statically attracted lint and dirt is to use a destaticizing air blow-off. One such system generates airborne ions with a weak radioactive source inside a blower housing. When this air is blown across the part, the ions neutralize static charges, and the air curtain gently blows away dust and dirt.

Vacuum removal of dirt at this stage is strongly advised to prevent soil redeposition. This step should immediately precede the painting operation, otherwise the parts can once again accumulate charges and become recontaminated.

Dust and lint is best controlled by confining all plastic painting operations inside a “clean room.” Such a room contains filtered air, and only authorized and properly attired personnel are allowed to enter.

**Mold release.** Mold-release agents are often used to facilitate withdrawing plastic products from their molds. Some mold releases will greatly interfere with paint adhesion. Probably the most notorious mold releases as far as painting is concerned are those containing silicone. Silicone materials have a way of spreading throughout a plant, causing untold problems with paint adhesion to plastic products. They can be spread by a plant’s air-conditioning system, contaminating parts stacked anywhere in a plant.

Wax-type mold releases can sometimes be removed by solvent cleaning, but are not recommended if parts are to be painted. Water-soluble mold releases can be removed with aqueous detergent solutions.

Sometimes mold-release agents are blended into a plastic formulation. These can migrate to the surface and cause paint delamination months or years after a part has been painted. Plastic raw materials are sometimes accidentally contaminated with mold release, either by the supplier or by the molder.

Certain types of plasticizers used in plastic formulations can cause problems with paint adhesion similar to mold releases. Plasticizers are added to some molding resins to increase impact resistance. The plasticizer can slowly migrate to the surface and soften the paint film, causing adhesion loss. Delamination of the paint film may occur weeks or months after the paint has been applied.

Tracking down the source of plastic surface contamination can require some disciplined detective work. In such an investigation, “no stone should be left unturned” until the source is discovered and eliminated.

**Preparing Plastic Surfaces for Painting**

Plastic surfaces are inherently smooth and tend to give poor paint adhesion unless the surface is treated. The most common way of overcoming this
Painting Plastics

smoothness is to microetch the surface with solvent to create a microroughness to provide anchoring sites for the paint. The etching is usually performed by the solvent in the paint being applied. This solvent must be selected carefully because different solvents etch plastics at varying rates. Insufficient etching will not provide proper adhesion; excessive etching can damage the plastic, exposing filler particles and in a few cases even creating sites for plastic raw materials to bleed into the coating. Some plastics, polycarbonate and polystyrene for example, will crack or become totally surface-crazed from solvent attack.

Plastics may have areas that are highly stressed from the molding process. Some solvents can form visible cracks in these areas due to stress-relief action. Many plastics can benefit from stress relieving by heating parts to 150°F for half an hour prior to painting. Overheating can distort sensitive parts, however, and parts with high molded-in stress are likely to warp.

Sometimes extra pockets of heat during molding will form highly cross-linked glazed areas that tend to resist solvent microetching. Unless additional steps are taken, paint adhesion will be poor in these areas. Tumbling in mildly abrasive media or blasting with light grit can deglaze these areas. Treatment in hot solvents or in solvent vapors also is effective.

When deglazing or solvent etching is not desirable, in particular with extremely nonpolar plastic surfaces, it may be necessary to use a chemical reaction to create polar oxidized groups on the surface. Two examples of plastics treated this way are polypropylene and polyethylene. These and similar low-polarity plastics may be quickly passed close to an oxidizing flame to form enough polarity in the surface to promote good paint adhesion. Putting parts through an electrical corona discharge has been used to cause a similar oxidation at the surface.

Low polarity plastics are frequently treated with photosensitizers and then exposed to ultraviolet light. The UV decomposes the photosensitive compounds to form free radicals that combine with oxygen in air to generate polar groups on the plastic surface.

Cold gas-plasma technology can pretreat plastics and dramatically improve surface properties for paint adhesion. Gas-plasma has been described as a “fourth state of matter.” If a gas is given enough energy, it becomes ionized (plasma). Examples include arc welding and fluorescent lighting, all of which involve a “glow” caused by excited ions falling to their lowest energy state.

The plasma reactor is typically a vacuum vessel with an access door for loading and unloading parts to be treated. Excitation is provided by a radio-frequency generator. When the reactor is started, a glow discharge can be observed. This process can use any gas or mixture of gases within the safety limitations of the system. Gases such as oxygen, nitrogen, air, helium, argon and ammonia are commonly used. Gas-plasma surface treatment microetches and activates the surface. A brief treatment will make the surface polar with a high surface energy so that coatings will wet it completely. Plasma processes usually do not change surface appearance; even inert materials can be plasma-treated without
Plastic Surface Peculiarities for Painting

A number of plastics have inherent properties that tend to cause difficulties in painting. In addition to the solvent sensitivity already described, these include:

- Water sensitivity
- Heat sensitivity
- Sanding sensitivity
- Nonconductivity
- Color matching with metal
- Gloss variations with metal
- Wicking

Water sensitivity. Aqueous detergent solutions can do an excellent job of cleaning plastics for painting. Water will neither corrode nor etch plastic. However, some plastics will absorb water, which can cause bubbles and blisters when the painted plastic is baked. Highly polar plastics such as nylon are

<table>
<thead>
<tr>
<th>Plastic</th>
<th>Heat Tolerance in °F</th>
<th>Plastic</th>
<th>Heat Tolerance in °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>170</td>
<td>Polyethylene</td>
<td>175-250</td>
</tr>
<tr>
<td>Acetal</td>
<td>220</td>
<td>Polypropylene</td>
<td>250</td>
</tr>
<tr>
<td>Acrylic</td>
<td>180</td>
<td>Polystyrene</td>
<td>130-145</td>
</tr>
<tr>
<td>Alkyd</td>
<td>300</td>
<td>Polysulfone</td>
<td>350</td>
</tr>
<tr>
<td>Cellulosic</td>
<td>220</td>
<td>PVC</td>
<td>170-225</td>
</tr>
<tr>
<td>Phenylene Oxide</td>
<td>180 &amp; Up</td>
<td>PVDC</td>
<td>170-210</td>
</tr>
<tr>
<td>Nylon</td>
<td>300-425</td>
<td>RIM</td>
<td>250</td>
</tr>
<tr>
<td>Phenolic</td>
<td>225-500</td>
<td>PRIM</td>
<td>250</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>250</td>
<td>TPR</td>
<td>250</td>
</tr>
<tr>
<td>Structural Foams</td>
<td>140-250</td>
<td>TPU</td>
<td>250</td>
</tr>
<tr>
<td>Polyester SMC</td>
<td>400 &amp; Up</td>
<td>TPO</td>
<td>230 &amp; Up</td>
</tr>
<tr>
<td>Xenoy</td>
<td>210-225</td>
<td>EPDM</td>
<td>225 &amp; Up</td>
</tr>
</tbody>
</table>

Figure 18-1. Plastics and Heat Tolerance Temperatures
especially susceptible to water absorption. Absorbed water can be removed by
drying the plastic at a moderate heat for an extended period.

**Heat sensitivity.** Heat used for dryoff or baking may cause structural shrinkage,
twisting or related distortion of plastic parts. The extent of the heat sensitivity will
depend upon the part configuration, the resin and the manner in which the part
was molded. Such distortion may sometimes be corrected by placing the part in a
fixture for rigidity and stress-relieving the part at a slightly raised temperature.
Figure 18-1 lists various plastics and their heat tolerance temperatures.

The thermal stability of many plastics is quite low. For example, the maximum
temperature that styrene parts should endure is only about 140°F. Acrylic and
ABS can withstand no more than about 180°F. Not all plastics will distort at these
low temperatures; polycarbonates and acetals will not distort below 275°F. When

<table>
<thead>
<tr>
<th>Problem</th>
<th>Probable Cause</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swirls</td>
<td>Compound or mold surface too hot</td>
<td>Adhere to recommended melt temperatures. Control mold temperatures carefully. Use high-volume solids primer filler and texture coating.</td>
</tr>
<tr>
<td>Pinholes/Craters</td>
<td>Solvent attack with accompanying release of gases</td>
<td>Use only mild solvent or waterborne primers.</td>
</tr>
<tr>
<td>Blisters</td>
<td>Absorption of solvent with subsequent release of gases</td>
<td>Air-dry, prebake or store foam part at room temperature for 72 hours before coating.</td>
</tr>
<tr>
<td>Bubbles in Substrate</td>
<td>Inadequate filling of mold, Inadequate foaming of part</td>
<td>Fill mold as fast as possible. Keep careful control of material-fill levels.</td>
</tr>
<tr>
<td>Poor Adhesion</td>
<td>Too much mold release</td>
<td>Use only minimal amounts of mold-release agents.</td>
</tr>
<tr>
<td>Wicking</td>
<td>Mold too hot, material too Viscous, solvent too active</td>
<td>Adhere strictly to recommended melt temperatures. Keep careful check of mold temperature through careful placement of gates. Use minimal amounts of mold release.</td>
</tr>
</tbody>
</table>

*Figure 18-2. Chart for Finishing Structural Foam*
heat-stability problems are encountered, the applied paint can often be baked at a low temperature for various lengths of time to achieve a full cure. However, long bake times increase costs by requiring slow line speeds and enlarged ovens.

**Sanding sensitivity.** Sanding to remove mold parting lines or other defects may open the air cells of structural foam parts. Air is deliberately molded into structural foam parts to economize on the amount of plastic that is used in the molding. The shapes of the air pockets provide a strength equivalent to or even greater than a plastic without such air cells. Such a sanding-caused porosity can lead to blisters and popping problems during baking. The sanded area may deglaze the plastic, resulting in a dull paint area that may require the entire part to be given a new prime coat. Figure 18-2 lists various problems, probable causes and remedies for finishing structural foam parts for business machines.

**Nonconductivity.** The minimal electrical conductivity of plastic prevents painting by E-coat. Plastics are also more difficult to paint electrostatically than metals. Conductive precoats can be applied to enable plastics to be electrostatically coated, but this creates an extra step in the coating process. Such a conductive coat can be applied by various methods, including dipping and spraying. Fast-evaporating alcohol solutions of conductive organic salts can be used as a “prep” coat to give a plastic part conductivity for electrostatic application. Aqueous solutions of calcium chloride and lithium chloride can also be used. The conductive coatings do not interfere with paint adhesion.

**Color matching with metal.** Color matching between painted metal and painted plastics can sometimes be a vexing problem. Different surface textures, substrate heat capacities and material densities can cause an apparent color variation. The different heat-up rates (heat capacities) of materials and different degrees of light reflection from their surfaces can produce color mismatches that can be extremely difficult to overcome.

**Gloss variations with metal.** Gloss variations between different plastics and between plastics and metals can occur, often for the same reasons that cause color differences. Spots that are sometimes called “dive-in” or “sink” are the result of different plastic densities from one location to the next in a plastic part and are caused by variations in the internal mold pressures across the part. Priming of such parts becomes necessary if uniform gloss across the entire surface is to be maintained.

**Wicking.** Air entrapment or solvent absorption along fiberglass/plastic interfaces can occur with fiberglass-reinforced plastics. This “wicking” of the solvent deep into the plastic results from the greater thermal expansion and contraction coefficients of plastics compared with the fiberglass.

When the plastic in the mold cools, it contracts to a greater degree than the fiberglass. The plastic shrinks away from the fiberglass, leaving microvoids that can act as small capillaries. As the paint is applied to this surface, the paint solvents are drawn deeply into the part at the fiberglass/plastic interface by
capillary action. Because the solvents have been pulled deep into the part, they often do not evaporate until after a skin has formed on the paint. By the time the plastic part is finally warm enough to evaporate the “wicked-in” solvent, the paint film has solidified to some extent. The solvent in the capillary is forced up under the skinned-over paint, forming a “pop” or blister.

Sometimes low-molecular-weight polymer molecules will cause an identical problem when volatilized in this fashion. Molding resins free of volatile materials should be used if the parts are to be painted.

Summary

The paintability of various plastics can be acutely different. It is unlikely that a truly helpful chart could be prepared that would give specific instructions for painting all types of plastics. It is not sufficient to specify that the plastic is a generic material such as phenolic, nylon or acetal, or a tradenamed plastic such as Noryl (General Electric’s polyphenylene oxide). Over 100 different grades of Noryl are available. In each case the specific plastic blend must be known to predict paintability. Even then, some trial-and-error experimentation will be needed to determine which coatings are suitable for a particular plastic part.
Chapter 19

The Curing of Coatings

The curing of a coating is the process of the freshly applied coating (liquid or powder) changing to a finished (solid) paint film. Coatings are of little value as they are applied; they must be converted to a finished paint film to perform either for appearance or for function or both. Liquid coatings convert to the cured state either by solvent evaporation only or by solvent evaporation plus resin cross-linking.

Powder coatings are heated to melt the individual particles and thus form a continuous film on coated parts. In roughly 98% of powder coating formulations the heat also initiates chemical cross-linking of the resin(s), although a few powder coatings simply melt without any cross-linking taking place. On cooling the molten film solidifies.

Coatings That Cure by Solvent Evaporation Only

A liquid coating that cures by solvent evaporation only has one or more resins with long-chain polar molecules dissolved in a solvent. As the solvent evaporates, the molecules are drawn together by polar attractive forces at numerous sites along their chain lengths; no chemical reaction takes place however. These are called “lacquer” paints.

If solvent is added to the dry (cured) paint film, the resin molecules will again go into solution. The solvent molecules will interfere with the polar attractive forces, allowing the resin to become fluid (dissolve). The addition of heat to this type of resin can also reduce the polar attractive forces, softening the resin.

Coatings that contain long-chain molecules and cure by solvent evaporation only are by definition lacquers. Lacquers can be made from any soluble linear polymer, such as chlorinated rubber, cellulose and acrylic. They characteristically have a high molecular weight, which gives good paint film properties. Their main
weakness is a lack of solvent resistance to the type of solvent originally in the coating. This weakness is also an asset in refinishing a lacquer; the paint film can be made to reflow to build up renewed surface smoothness.

Although lacquers can air dry, they can also be processed (cured) in an oven. The only function of the oven is to speed the solvent evaporation.

Because of their high molecular resin weight, a lacquer’s solvent content is necessarily high. A lacquer may be as much as 90% solvent and only 10% solids. Because of EPA emission limits for volatile organic compounds (VOC), lacquer use has declined considerably.

Lacquer-type powder coatings likewise do not cross-link; they only melt and solidify upon cooling.

**Coatings That Cure by Cross-linking**

All coatings that cure by cross-linking are categorized as “enamels.” This applies to both powder and liquid coatings. A liquid coating that cures by cross-linking contains one or more partially polymerized resins that are dissolved in a solvent. As the solvent evaporates or as heat is applied, a chemical reaction occurs either among the resin molecules or with molecules of another cross-linking resin so that chemical bonds are formed. The newly formed chemical bonds cannot be dissolved by adding solvent.

Coatings that cure by cross-linking can be divided into at least five categories:
- Oxidizing
- Moisture cure
- Heat cross-linking
- Catalytic cross-linking
- Radiation cross-linking

**Oxidizing Coatings**

These liquid coatings use resins based on drying oils. The resins may be alkyds, phenolics, oil-modified urethanes, epoxy esters and various oleoresinous systems. Some have drying oils added to facilitate air dry curing. After the coatings are applied, the solvent begins to evaporate, exposing the unsaturated resin to the air, triggering a cross-linking reaction with atmospheric oxygen. These resins and their modified chemistries contain molecules with carbon-to-carbon double bonds that react with oxygen to form peroxy and then later ether cross-linkages (oxidative cross-linking). This will occur slowly at room temperatures and faster at elevated bake oven temperatures.

**Moisture-Cure Coatings**

This category of liquid coatings functions in a similar matter to oxidizing
systems. After the paint is applied, moisture in the air will begin to react with the coating’s resin, triggering cross-linking. An example of this type of coating is a moisture-cured urethane, in which isocyanate groups react with moisture to form a urea linkage. As with oxidizing systems, elevated temperatures can speed the curing process.

**Heat Cross-linking Coatings**

Another category of liquid coatings exists that either cure extremely slowly or cannot cure at all by air drying and requires heat for curing. Their essential composition consists of a main uncross-linked resin, such as acrylic, and an uncross-linked “cross-linking” resin, such as melamine. The two resins are blended with solvent, other additives and, perhaps, pigment.

Once the container is opened and the coating is applied, solvent will begin to evaporate, but little or no curing will occur at room temperature. The applied coating will merely remain tacky (sticky) and uncured unless heat is applied. The temperature must reach or exceed a level that triggers cross-linking of the resins. In the example of the main acrylic resin and the melamine “cross-linker,” the resultant cured paint film is called a melamine-cured acrylic.

Heat cross-linking coatings can have various types of main resins and cross-linking resins. Whatever the resin types however, the basic principle is the same: a certain temperature is required to trigger cross-linking and curing. For many high-solids coatings the cross-link temperature is well above room temperature. Such paints can remain tacky for years without curing.

All enamel-type powder coatings, which is nearly all of them, fall into the heat cross-linking category.

**Catalytic Coatings**

This category of coatings consists of two parts: the major coating component and a lower-volume catalyst component. The major coating component contains mostly resin, various additives, solvent and, perhaps, pigment. The catalyst component contains essentially only solvents plus the catalyst. As long as the two components are kept separate, each remains essentially unchanged in a fluid state. Once the two components come together, cross-linking begins between the resin and catalyst, and curing is the ultimate result.

An example of a catalytic coating is a two-component urethane consisting of a polyester resin and an isocyanate catalyst. When the two are intimately mixed, a cross-linking occurs that forms a “urethane” linkage, thus the resultant coating is called a urethane. The coating can be mixed in a single container and then applied,
or the two components can be brought together in the atomizing portion of a spray gun and mixed.

The applied coating will cure with or just before application without applied heat. However, elevated temperatures will speed the rate of cross-linking and solvent evaporation.

When the two components are mixed together, the resultant mixture has a “potlife.” If the mixture is allowed to remain in the container, total cross-linking will occur over a predetermined period of time, and the mixture will become hard. Formulating chemists are able to control the rate of cross-linking and the resultant potlife to various degrees. The potlife can be controlled to be as brief as a few minutes or as long as 16 hours. If the pot life is exceeded, excessive cross-linking lowers the film quality even though the paint may apply properly and look normal.

Figure 19-1. Vapor Injection Curing (VIC) Coating/Catalyst Mixing Schematic
Catalyst Vapor Coatings

Known as “vapor curing,” this process uses a room-temperature vapor catalyst to speed the curing of certain two-component formulations. After the two components are applied, the coated parts are conveyed into a chamber filled with diethanolamine vapor, which accelerates the ambient-temperature rate of urethane production from the reaction of isocyanate and hydroxyl groups. The catalyst reduces the cure time to about 5 to 10 minutes.

The catalyst concentration is held at 1200 to 1500 parts per million. Air seals at the entrance and exit of the curing chamber contain the catalyst. The vapors and liquid of diethanolamine are safe and nontoxic, but they have a fish-like odor. They are scrubbed from the oven exhaust with water to prevent their release into the environment.

A low amount of heating is usually employed after the vapor chamber to drive out solvents. This low heat requirement can be an advantage when painting large or thick castings and similar parts. It avoids the long, slow heat-up and cooldown times needed for oven baking of coatings on massive metallic substrates or on parts with large heat capacities. Catalyst vapor curing can also be used on heat-sensitive substrates such as paper, cloth, wood and plastic.

A variation of the catalyst chamber process, called vapor injection curing (VIC), injects catalyst vapors into the atomizing air supply of air spray and air-assisted airless spray guns (catalyst vapor injection curing), as shown in Figure 19-1. It can also be introduced into the shaping air (air shroud) of rotary bell paint applicators. In this way a separate catalyst chamber stage can be eliminated from the coating process.

Radiation-Cure Coatings

This category of coatings contains various accelerators or catalysts that are dormant until acted upon by either ultraviolet (UV) light or electron beam (EB) radiation. The UV light or electron bombardment triggers a free-radical reaction among chemical groups that results in cross-linking (curing).

**UV-cure coatings.** These coatings contain chemical photoinitiators that are sensitive to UV light, which changes the chemical bond structure of the photoinitiators, forming free-radical groups that trigger resin cross-linking. These coatings may or may not require solvent or other fluidizing media to reduce viscosity to promote flow-out. If solvent is used, a flash-off time is allowed after application prior to UV cure. If the fluidizing media is a cross-linking material, called a “reactive diluent,” no flash-off time is required. Because rapid, extensive resin cross-linking can be initiated with UV light, extremely low-molecular weight resins are possible in the coating formulation.
UV cure is accomplished in enclosed chambers saturated with high-intensity electrically generated UV light. For total curing to take place, the UV light must activate all of the photoinitiators, which means that the light must “see” them. Only about 1 mil dry film thicknesses of pigmented coatings can be UV cured because the pigment molecules block UV light from some of the photoinitiators.

UV light energy decreases with the square of the distance between the light source and the surface receiving the light. Therefore, the UV light source is kept as close to the painted part as possible. For this reason UV cure is used mostly on flat surfaces, which can be kept very close to the light source. However, highly polished parabolic reflectors enable certain types of three-dimensional items to be UV-coated. These include wall emblems, golf balls and wood gun stocks.

UV curing is fast—usually in 10 to 60 seconds, which permits UV ovens to be confined and compact. The quick cure minimizes substrate heating, which is a great advantage when curing films on heat-sensitive substrates such as printed circuit boards, wood and thermoplastics. Fast “on-off” UV lamps allow starting and stopping the coating line quickly. The high heat from the lamps requires that they be turned off whenever the production line stops.

**EB-cure coatings.** These coatings are formulated to cross-link when radiated with electrons. As with UV curing, only a limited variety of EB-cure coatings is available. The electrons are emitted by a radiation source that is dangerous to humans. Therefore the radiation source must be shielded and the electron emission area designed with safety interlocks to prevent humans from accidentally getting close enough to be harmed.

EB systems require an inert gas flush such as nitrogen or argon to keep air out of the electron radiation area. This is necessary because electron radiation in air creates ozone and mixed oxides of nitrogen, which are harsh irritant gases that present severe health hazards for humans (even at low concentrations). Humans must also be kept out of the inert gas because of the danger of asphyxiation from the lack of oxygen.

This method of initiating chemical cross-linking is in many ways similar to UV curing. Not surprisingly therefore, some of the same advantages accrue with both UV and EB curing. EB curing is much faster than UV curing. The thickness of the coating is not a problem in EB curing; electrons are far more penetrating than UV light. The quick start and stop, the low space requirements, the minimal substrate heating, the low or zero VOC emissions and the rapid production rates possible for UV curing are also advantages of EB curing.

The electron beams lose their energy rapidly as they travel away from the generating source. A 6- to 8-inch target distance is about the maximum possible. It is mainly a “line-of-sight” curing process when metallic substrates are involved; electron beams will not penetrate metal. A slight amount of reflected beam curing can occur.

At first it might be expected that EB curing would be ideal for curing paints on heat-sensitive substrates. This is only somewhat true. EB curing is not well suited
for the general curing of coatings on plastic parts because polymeric substrates do not readily block the passage of electron beams. The penetrating electron beams can cross-link the underlying plastic substrate as well as cure the paint resin. Substrate cross-linking can dramatically reduce the plastic's impact strength by excessive embrittlement. This is another drawback of EB curing.

### Types of Ovens

The main types of coating curing ovens are convection and infrared. Both have the same goal: to heat the applied coating to its curing temperature. Natural or propane gas is the fuel more often used for convection ovens; gas or electricity can be used as the energy source for infrared ovens. In most locations electricity is more costly for heating than gas, but electric infrared ovens are easier to regulate and have a faster start-stop response.

#### Convection Ovens

Convection ovens heat the applied coating by first heating the oven air, which in turn heats the coating. Convection ovens are of two types: direct-fired and indirect-fired.

Direct-fired ovens heat the oven air directly with a source of heat, generally a gas flame. The flame's products of combustion are present throughout the oven, including where the coated parts are being conveyed through the oven. The combustion products may discolor or wrinkle some types of coatings.

For fine finishes it may be necessary to separate the oven burner combustion products from the curing chamber.

Indirect-fired ovens confine the source of heat to a separate enclosure and exhaust the products of combustion to a stack outside the plant. The walls of the "fire box" get hot and warm the surrounding air in the plenum section of the oven. A blower circulates the air from the plenum and in the oven to maintain a constant temperature throughout. A sufficient amount of fresh air is brought into the curing section, and the same amount of oven air is exhausted. This air exchange prevents the dangerous buildup of solvent within the oven, which could cause an explosion.

Normally the maximum allowable concentration of flammable vapors in an oven is limited to 25% of their lower explosive limit (LEL). LEL refers to the leanest combustible air/solvent mixture expressed in percent vapor by volume. In actual practice the volume of solvent vapor in the oven is generally far lower than 25%. Many ovens are operated at 3 to 7% of the LEL. Oven air volume turnovers per minute generally range from two to 10, depending on oven loading levels.

To save energy, monitoring systems have been installed by some plants to
minimize the fresh air makeup needed in the oven. Insurance companies generally permit ovens so equipped to be operated as high as 50% of the LEL value. The problem is that curing is not always efficient at 20% to 50% of the LEL. Nevertheless, hot air dilution of solvent vapor to lower concentrations than necessary is a waste of fuel. A study by a U.S. automaker revealed corporate-wide energy waste in this regard. The company’s paint ovens were operated at an average 2% of the LEL; the highest single vapor concentration was only 8% of the LEL. Fresh air turnover rates were reduced sharply, producing an enormous annual dollar savings.

Many other techniques can be used with curing ovens to conserve energy. One is to use air seals or “bottom entry and bottom exit,” which confines the oven’s hot air inside where it belongs, since hot air rises. Bottom entry/exit is better than air seals, but a combination of both is the most energy efficient design. Another is to fully insulate the oven. Another is to operate the oven at the exact temperature required to elevate the applied coating to its precise curing temperature for the specified amount of time.

A variation of conventional indirect-fired ovens uses high-velocity recirculating oven air that is impinged directly onto the applied coating. These are termed “high-velocity ovens.” The rapid exchange of air heats the coated parts quickly, allowing the conveyor speed to be increased.

Gas is usually the source of heat for indirect-fired convection ovens. Oil can be used; so can electricity. The oven shape varies with the product being coated; it may be square or long and narrow. Low-volume finishers may use a batch oven, which has a door for access.

Infrared Ovens

Infrared ovens use a radiant energy that passes through the oven air without heating the air. Some air heating occurs because of the heat-up of the coated parts and of the oven walls, which generates a modest amount of convection heating. The energy is converted to heat when it strikes a surface, such as the coated part. The source of infrared heat may be electric heating elements of various types and configurations and may also be gasfired.

A properly designed infrared oven directs the radiant heat as efficiently as possible onto the coated surfaces. Most infrared ovens use tubular lamps, quartz glow bars or filament-wound ceramic cones to emit the energy. The wavelength output of the radiant energy varies slightly with each source. Each of these uses polished reflectors behind them to direct the reverse side radiation toward the painted parts being cured.

Studies have shown that gold-coated reflectors, although more costly initially, surpass the others in infrared reflecting efficiency and are ultimately the most...
economical choice. Figure 19-2 shows some painted parts being conveyed through an infrared oven equipped with gold-coated reflectors. Gas-fired black-surface infrared ovens are not as common and are less easy to control but are just as effective as electrical infrared ovens in curing paint films.

Infrared radiation is often the best method to cure powder coatings because no air blows through the oven to disturb the powder before it melts and cures. Fast heat-up rates can be achieved with infrared, which is highly desirable for optimum powder coating appearance. Ideally, powder coatings should melt and flow out before cross-linking takes place. If heated slowly, powder coatings may undergo considerable cross-linking; complete melting and flowout may never occur. Fast initial heating of powder coatings gives a noticeably smooth and uniform paint finish.
Other Curing Methods

Various other curing methods have been devised, none of which is in much use. These include induction heating, radio frequency (RF) curing, microwave curing and heat-of-condensation curing.

Induction Heating

For induction heating, a source of low-frequency alternating current is placed close to the freshly coated metal. The rising and falling electromagnetic lines of force from the alternating current induce powerful circulating currents in the metal, creating a rapid temperature rise both in the metal and coating. Carefully regulating the alternating current can control the induced current and the resulting temperature rise in the metal and coating. To be successful, the source of alternating current must be very close to the coated metal.

Induction heating has been used successfully to cure coatings applied to a moving strip of metal (coil coating). An advantage in induction heating is that metal can be heated almost instantly, eliminating the need to have large convection ovens.

Microwave and RF Curing

This type of curing is similar to induction heating. The only difference is in the frequency, which is in the thousands of cycles per second. The disadvantage of RF curing is that the source of RF energy becomes a radio transmitter, creating a powerful RF signal at the particular frequency being used.

Heat-of-Condensation Curing

Two companies reportedly explored the possibility of using the heat of condensation to generate heat for curing. When hot vapor is allowed to condense, a large quantity of heat is given off. In a refrigerator cycle the evaporator inside the refrigerator allows a liquid compressed gas to expand, which absorbs heat, keeping the inside of the refrigerator cold. The compressor, located outside the refrigerator interior, forces the expanded gas vapor back to a liquid, giving off heat through coils behind or under the refrigerator. Usually a fan blows ambient air across the condenser coils to help remove this heat. On a large scale, such heat could conceivably run a curing oven.

These are rare curing methods, but the future is something at which we can only guess. Some years before vapor curing was a commercial reality, opinions were expressed by painting “experts” that catalyst vapors to cure paint would never be used outside a test laboratory.
Chapter 20
Defects in Applied Liquid Coatings

This chapter deals with the various types of defects found in cured liquid coating films. Electrocoating and powder coating defects were discussed in chapters dealing with those subjects.

The types of defects are various and sundry. However, all paint defects have one thing in common: a cause. The cause is always due to the breakdown of good painting practice—somewhere along the line—from cleaning and pretreatment to paint application and curing.

Tracking down the cause of a paint defect ought to be straight forward. The secret of good “detective work” with paint defects is to build solid foundations of knowledge in good painting practices and in painting defects. A painting defect is like a sign along a highway—it gives information that leads to a goal—getting to where one wants to go. The defect always points to a violation of good painting practice or an inadequacy of the substrate.

A comprehensive list of painting defects could include perhaps several hundred names. Such a long list can be shortened considerably by limiting it to the major types of defects. By and large, these major defects come close to covering all types of defects. The defects that will be covered are:

- Blisters
- Bubbles and craters
- Color mismatch
- Dirt
- Fisheyes
- Gloss variations
- Mottle
- Orange peel
- Runs, sags and curtains
- Paint adhesion loss
- Soft paint films
Blisters

Definition

A blister in a paint film is a small dome-like raised area that contains, or at one time contained, moisture (water, water vapor or both).

Causes

Metal

Blisters on painted metal are traceable to contamination left on a surface prior to painting, either from water, residual soils, poor rinsing or incomplete dryoff of rinse water. Fingerprints may contribute salts or skin oils that can lead to blisters. Any unrinsed cleaners, pretreatment chemicals or unremoved greases and oils can permit moisture to get under a paint film in a matter of days and form a blister. The moisture can also come from poor water removal in a compressed air supply, although when that occurs, it tends to cause a large, obvious flaw in a paint finish.

Moisture in or under a paint film produces rapid blistering, expanding and contracting with temperature change and lifts the film. The moisture strains a paint film to the point that cracks may appear. A paint film is unable to resist this movement because of reduced adhesion at the part surface. Once the film cracks, moisture easily reaches the underlying surface, and corrosion can begin.

Inadequate rinsing or rinsing with water containing high amounts of dissolved solids can sometimes cause a problem. When these difficulties are experienced, it may be necessary to use ultrapure rinse water containing as little as 10 parts per million total dissolved solids. The paint system being used is the major determinant of the dissolved solids that can be tolerated in rinse water. In some cases 200 to 300 parts per million dissolved solids may be adequate to avoid rinse water deposits. Tap water rinses may be followed by a brief misting with deionized water to eliminate blisters from this source.

Blisters can be produced on painted parts by osmosis. When a semipermeable membrane separates solutions of different concentrations, the solution with the lesser concentration will seep into the solution with the higher concentration because of osmotic pressure. Such a scenario is formed with a paint film when solid residues remain on the surface of a substrate beneath the paint film. When the paint film gets wet, moisture will seep through the paint film, contacting the residues, forming pockets of concentrated solutions. Osmotic pressure will draw additional moisture from the top of the paint film through the paint film to the concentrated solution sites. When a sufficient amount of moisture has been drawn
through the paint film to the pockets of solutions below, the paint film will be lifted from the substrate at the solution sites in the form of blisters. (Osmotic pressure can be amazingly high; osmotic pressure forces water to the topmost leaves of tall trees.)

**Wood**

Blisters on painted wood are usually caused by moisture escaping from the wood to the wood/paint film interface. When the moisture gets warm, it expands, exerting enough pressure to raise the film into a blister.

**Prevention**

To prevent blister formation on painted metal, be absolutely certain that the surface is free of contaminants before applying the paint. Be sure that the gun air supply is clean and dry.

To deter blister formation on wood (in addition to the cleanliness precaution for metal), make sure that moisture can find another exit route out of the wood instead of pushing up through the paint film.

**Bubbles and Craters**

**Definition**

A bubble in a paint film is a small dome-like raised area that contains (or earlier contained) solvent vapor. A bubble closely resembles a blister (which contains water and/or water vapor).

A crater is a small, concave depressed area that formerly was covered by a bubble, as shown in Figure 20-1. The breaking of the bubble contributes to the crater’s rounded bottom and built-up sides.

![Figure 20-1. Cratering](image-url)
Causes

Bubbles tend to form during a bake cycle when the top layer of the paint film skins over before most of the solvent in the film has had a chance to escape. The rising solvent pushes up portions of the skinned-over top layer, forming bubbles. If the bubbles break, the raised skinned-over areas constrict to the sides, forming craters. These defects are rarely seen on air-dry finishes because ambient air tends to allow most of the solvent to escape before the film skins over. Bubbles (and craters) are usually traceable to the following causes:

**Inadequate flash time before the bake cycle.** This leaves an excessive amount of solvent in the paint film. The bake oven heat may skin over the film before most of the solvent has escaped.

**An extra heavy wet film application.** This can trap large amounts of solvent in the film. The bake oven heat may skin over the top layer of film before most of the solvent has escaped, forming bubbles.

**A solvent blend that evaporates too slowly.** This will invite skinning over of the top layer of film before most of the solvent escapes, forming bubbles.

**Insufficient primer bake.** This can leave an excessive amount of solvent in the primer, which may form bubbles in the subsequently applied topcoat during the topcoat bake cycle.

Prevention

The best ways to prevent bubble (and crater) formation are to allow enough flash time before a bake cycle, apply a coating in several thin layers (rather than one thick layer), use the proper solvents and maintain specified primer bake cycles.

Color Mismatch

**Definition**

Color deviations from one part to another are shifts in the color of a paint film that occur in applying the same batch of paint. These color deviations are totally independent of “metamerism,” which is a color shift due to a change in the nature of the incident light. Color mismatch between separate batches of the “same” paint are the fault of the coating manufacturer.

**Causes**

The causes of color deviation can include:
Variations in the degree of film wetness. The degree of film wetness can affect the shade of a metallic paint. The wetness affects the relative distribution of color pigment particles and metallic flakes. In general the drier a metallic paint is applied, the lighter it appears.

Inadequate agitation. Improper agitation of the paint can leave uneven pigment distribution, which will cause color deviation. The paint may not have been thoroughly agitated in its container before being put into the paint application circulation system. The pigment portion of nearly all paints will settle during use if the paint is not agitated at least occasionally throughout use. Inadequate mixing will result in the alternate application of resin-rich paint and pigment-rich paint.

Low film builds. Excessively thin films may fail to hide the substrate thoroughly. Some colors are far more effective in hiding than others. Light colorcoats often require a greater film thickness to hide a given substrate completely than do darker shades.

Different application procedures. Various application procedures can produce different apparent colors with the same paint. Paint applied with air spray may have a different shade than the same paint applied by a centrifugal rotary applicator due to different degrees of atomization and particle delivery velocities. Electrostatic versus nonelectrostatic application can produce color deviations as well.

Different substrates. Even if the same paint is applied with the same application device at the same time, the color may look different if the substrate material varies. If an assembly of plastic and metal is painted, a variation in the shades of color may occur. This is thought to be due to the different heat-up rates (heat capacities) of metals and plastics during the curing process. The paint on the plastic could remain wet for a longer period than the paint on the metal, or vice-versa, allowing variations in the rates of pigment separation. This is less likely to be a problem with an air-dry paint than with a baked finish.

Overbake. Baking either too long at normal temperatures or at overly high bake temperatures can darken light colors. Some paints seem to be much more sensitive to this than others. Oven loading rates can complicate the situation. Since the heat removal is less when only few parts are in the oven, the tendency to overbake is greater when the conveyor line is fully loaded.

Prevention

The prevention of color deviations requires absolute consistency in paint
agitation, degree of film wetness, film thickness and application procedures. Color shifts with widely different substrates such as metal and plastic can be prevented in some instances by baking each substrate separately with different bake cycles. Perceived color shifts with different surface textures can be prevented by eliminating the differences in texture (changing the product design). These so-called “solutions” to the problems of color mismatch are often impractical, however.

**Dirt**

**Definition**

Dirt in paint or in painted surfaces is defined as any and all contaminants, including lint, dust, small clusters of improperly mixed pigment, tiny particles of overspray paint debris and oil mist.

**Causes**

The causes of dirt in paint or in painted surfaces can almost always be traced to inadequate facilities, poor housekeeping or to poor painting practices. Some of the causes of such dirt include:

**Lint.** This is one of the most frequently found paint contaminants. Lint can originate from cardboard package interleaving, cartons, boxes, masking paper, shop cloths, clothing, etc. A large plant conducted a detailed study on the nature of the contamination in its painted products and discovered that over 50% of the dirt was attributed to various types of lint fibers.

**Overspray.** A common source of dirt is overspray paint that dries and accumulates on various objects in the spray booth. The overspray can disintegrate into tiny particles that can work their way into the applied paint. Improperly balanced air flow in a spray booth may contribute to extensive overspray accumulation.

**Ruptured, loose or missing filter elements.** Poor filter maintenance, whether for paint or for air makeup/air exhaust, can contribute dirt in paint. Clogged air filters, for example, can add dirt by reducing either makeup or exhaust air flow and can themselves be a source of dirt by having debris collect on and fall off the filters.

**Dust.** Airborne dust can be generated in the painting area by many sources, which may include dirty floors, dirty conveyors, fans, forklifts and sanding processes. Sanding rework is often performed just outside the paint booth because of the convenience of location. Sanding should be done as far from the spray booth as possible.
as possible and kept in a confined area with separate and filtered ventilation to contain the sanding dust.

**Inadequately cleaned paint delivery piping and tubing.** Paint piping and tubing that are seldom cleaned can be a source of pigment cluster and resin globule formation.

**Inadequately stirred paint.** Lack of thorough paint agitation before using can sometimes cause pigment clustering and spray gun "spitting," which is particularly true if stored paint is nearing the end of its shelflife.

**Reduction with improper solvents.** Adding thinners of the wrong polarity can force resin out of solution. Soft lumps of the resin may readily be squeezed through filters and end up in the finish as visible clumps.

**Dirty paint from the supplier.** Paint can be contaminated with dirt when delivered from the coating manufacturer. This is not very common, but it does happen. Occasionally an uncleaned tote tank or dirty pails are inadvertently filled with paint.

### Prevention

Eliminating dirt in paint or in painted surfaces should be a daily priority assignment for everyone in the painting department of a plant. Sharp vigilance must be maintained in the following areas:

**Lint.** All possible sources of lint should be minimized in the paint department, which if possible should be a closed and restricted area. Only authorized persons properly attired with lint-free outer wear should be allowed to enter. Doors should be opened only for authorized personnel access.

**Overspray.** Spray booth air balance should be checked regularly to confine overspray to where it is supposed to go. Booth doors should be opened only by authorized personnel and closed promptly, not propped open.

**Filters.** Periodic cleaning or replacement of air filters in the compressed air line helps prevent particle accumulation and dirt. Filter booths that draw plant air into the spray zone must have tight-fitting intake filters with a pore size small enough to remove fine dirt. Flash zones must receive the same timely maintenance.

**Dust.** Dust can be controlled by converting the painting area into a “clean room.” Incoming air should be filtered; shoe baths and blow-off vestibules are helpful; sweeping should not be permitted—only wet mopping. Tack cloth wiping of products prior to painting can be an asset. Ionized air blow-offs can be directed onto plastic parts, which tend to attract dust. It is prudent to cover pallets of parts that are awaiting painting to protect them from possible contamination by oil mist, dust and particulates present in plant air. Sheets of inexpensive polyethylene are suitable for this purpose.

**Inadequately cleaned paint piping and tubing.** Simply flushing thinner through
paint piping and tubing until the solvent is clear often does not do an adequate job of removing the old paint. Blends of aggressive solvents can be purchased that are specifically designed to clean paint lines before they are used for a new color. Plants that use such solvents for the first time are always amazed at the material removed from supposedly “clean” paint lines.

Inadequately stirred paint. Paint should be thoroughly agitated before and during use. If minor amounts of pigment cannot be redispersed, it is satisfactory to filter the paint carefully before using. If appreciable quantities of pigment have settled out of the paint, the coating must be discarded or returned to the supplier. Coatings that are well past their normal shelflife may have formed irreversible pigment seediness.

Reduction with proper solvents. The only solvents that should ever be used for reducing paint viscosity are those recommended by the paint suppliers.

Dirty paint from the supplier. Paint should always be carefully filtered immediately before use. The paint from the supplier may well be perfectly clean. Last-minute filtering before painting eliminates any possible accidental contamination and can prevent untold quality problems.

Fisheyes

Definition

A fisheye defect in a paint film is a small depression (crater) with a mound (dome) in the center. The resemblance to a fisheye is the roundness of the depression (the outer circle of a the eye) and the central mound (pupil).

Causes

This defect is nearly always caused by residual oil or grease, especially silicone types. Silicone materials may be accidentally introduced onto surfaces of previously cleaned parts or may contaminate parts not completely washed free of silicones during prepaint cleaning operations. Silicone molecules are extremely polar and thus make very tenacious lubricants for metal surfaces. However, this characteristic makes them difficult to remove as well. Tiny quantities of silicone in sanding dust, or on contaminated paper or cloth towels or from mold releases and polishes sprayed at a considerable distance from parts yet to be painted can cause serious fisheye problems. Because the silicones are so polar, paint tends to “crawl” away from spots of silicone contamination into itself. This forms a small dome of silicone barely covered with paint sitting in the center of a depression.

So many different silicone-containing materials are used that it is impossible to identify a single solvent that is able to dissolve whichever silicone contamination
might be present. Various silicones are found in hand creams, hair sprays, polishes, mold releases, rubber seals, waxes, gaskets, lubricants and in many other products as well. One corporation traced the source of its daily fisheye problem, which always occurred between 10 and 11 a.m., to a glass cleaner being used by a vending machine attendant.

Prevention

To avoid silicone-caused fisheye problems, keep silicone products out of a plant that does painting. Employees should be instructed to avoid bringing silicone-containing products into the plant. Where the problem already exists, the contamination must be removed. Mechanical abrasion may be effective, but care must be taken that the sanding debris does not recontaminate other parts. Solvents that have had good success in removing various silicone materials include butyl acetate; 1,1,1-trichloroethane; and trichlorotrifluoroethane.

Materials sold as “fisheye eliminator” are designed to be added in small amounts to the paint and mixed in before application. Roughly 0.2 to 2.0 mL are used per gallon to reduce the tendency for the paint to pull away from the oil remaining on surfaces to be painted. The fisheye eliminators tend to work well. They contain molecules that have a polar end and a nonpolar end. The polar portion is compatible with the highly polar silicone material, and the nonpolar part of the molecule mixes readily with the less polar paint molecules. (Soaps and detergents have similar molecules that are co-soluble to remove nonpolar oil and grease, dispersing them into water that is quite polar.)

Although fisheye eliminators are effective, routine use is generally not recommended. Fisheye eliminators can actually cause fisheyes by interfering with adhesion when repainting over a coating that has had fisheye eliminator added to it. This situation can be acute when touchup is performed on rework parts. Fisheye eliminator can be nearly impossible to clean out of paint pots and lines. Sometimes continued use of the eliminator is required to prevent fisheyes, even though the silicone contamination on the parts has been corrected. In such situations a possible solution is to wean the system from fisheye eliminator with gradually diminished amounts of the additive. Do not use fisheye eliminator on a constant basis as a means to circumvent inadequate cleaning of parts. Finding the source of contamination and using fisheye eliminator at all is best.

Gloss Variations

Definition

Gloss is a measure of the capability of a surface to reflect light. A painted surface with a high gloss reflects considerable light; one with a low gloss reflects
little light. Gloss-deficient patches of paint film can sometimes occur and are known as “flat spotting” and “striking in.”

Causes

The causes of gloss-deficient patches can include:

**Wet spots in a basecoat.** Point-to-point gloss variations may be caused by wet spots in a basecoat prior to topcoating. The wet spots arise from improper application techniques. Extra wetness at any area can allow minor pigment floating that can appear as decreased gloss or increased gloss.

**Insufficient oven makeup air.** Insufficient fresh makeup air in the oven may cause paint dulling. Few ovens are ever found to be operating at air turnover rates that are too low. However, occasionally solvents need to be swept out rapidly to prevent their dulling the paint. When direct-fired ovens are used for curing, the solvents in combination with oven combustion products can contribute to poor gloss formation.

**Excessive humidity in the flash zone.** Excessive humidity in the flash zone, particularly with paints that contain fast evaporating solvents, can add small amounts of fine water droplets to the paint film. This “blushing” is caused whenever so much evaporative cooling takes place that the surface temperature of the paint film drops below the dew point. Minor blushing may be perceived as low gloss because of its dulling effect on the paint film.

Rarely do plants experience true blushing any more because so few low-solids lacquer paints are still used industrially. Blushing results in a distinct whitish haze due to condensation of water droplets in the wet film. Minor blushing can generally be buffed out, but in more pronounced cases repainting is necessary. Usually not enough water condenses into the film to cause a whitish blush, but only enough to lower the overall gloss levels.

**Insufficient film build.** Low film builds do not permit the paint to flow sufficiently for good gloss. Variations in film thickness can therefore produce nonuniform gloss.

**Excessive oven temperatures.** Excessive oven temperatures can sometimes cause a dramatic reduction in overall gloss. Each paint is different in this respect. Dark shades are most likely to exhibit reduced gloss if cure temperatures are too high.

**Molded plastic density variations.** Point-to-point density variations can occur in molded plastic parts due to unequal mold filling and unequal mold pressures. These density differences cause varying degrees of solvent adsorption and evaporation with subsequent differences in gloss level from one spot to another.

Prevention

Gloss-deficient areas can be prevented by a six-point program:
- Make sure that plastic parts are free of density variations by priming them first
- Employ proper paint application techniques
- Maintain consistent paint film thickness
- Avoid excessive humidity in flash zones
- Make certain that oven makeup air is sufficient
- Operate bake ovens at specified temperatures

Mottle

Definition

Mottle occurs when metallic paint is applied excessively wet and color pigments separate from the metallic flakes. The separation of pigments creates darker “rings” of color that deviate from the overall color; metallic flake forms light regions in the centers of the rings.

Causes

The cause of mottle is almost always traceable to applying paint extra wet (containing excessive solvent). Many colors are blends of two or more pigment materials whose densities may differ widely. When non-metallic paints are applied overly wet (flooding), the pigments may tend to separate; one pigment may seem to float. The result is a dark visible appearance where color float occurs.

If metallic paints are applied extra wet, solvent evaporation cooling at the surface can cause minor circulation patterns known as Benard cells. The swirling action sweeps the finely ground color pigment to the edges of the cells and leaves the metallic flake in the center. Because of their size and weight, the metallic flakes are not readily moved by these miniature circulation patterns in the drying paint film. This gives rise to dark rings of color pigment particles with light centers because of increased concentrations of aluminum flakes. When applied too wet, light-colored metallic paint is especially prone to this visible separation of metallic flakes and pigment particles.

A related defect in metallic or nonmetallic films is sometimes caused when extra paint, either due to surface tension or because of electrostatic attraction, accumulates on the edges of panels. This extra paint requires increased drying or cure time, occasionally allowing pigments to “float” to the surface, leaving a dark line around all four edges of panels. This defect is frequently referred to as “picture framing.” (Metallic paints sometimes undergo pigment clumping when
applied electrostatically, but that is not related to mottle.) It is caused by charge accumulation on the metal flake pigments.

**Prevention**

Pigment separation from the metallic flake can usually be prevented by not applying the paint too wet. Applying the initial coats at normal wetness and the final wet-on-wet coat somewhat dry can help prevent mottle.

Pigment clumping in metallic paint applied electrostatically can usually be prevented by using grounded paint hoses.

**Orange Peel**

**Definition**

Orange peel in a paint film is characterized by repetitive bumps and valleys similar to the surface of an orange, as shown in Figure 20-2.

**Causes**

Orange peel results when the freshly applied paint film does not flow out smoothly. The causes of poor flow-out are usually one of the following:

**Excessively dry spray.** This occurs when excessive solvent evaporates from the atomized paint particles either en route to the target or too quickly after reaching the target so that satisfactory paint flowout is impossible. Excessive solvent evaporation on route to the target can be caused by overatomization, a solvent that is too fast and by too much distance between the gun and target. Over-atomization creates excessive atomized particle surface area, increasing solvent evaporation. Excessive distance between the gun and target can occur from poor operator technique. For example, too wide a spray fan pattern can make the spray at the edges travel an excessive distance to the target. Excessive solvent evaporation after the atomized particles are deposited on the target may be caused by maintaining high booth temperatures or high part temperatures, and by an improper solvent balance.

**Poorly atomized spray.** This can be caused by insufficient atomizing air pressure and overly high paint viscosity.

**Overly thin coatings.** Overly thin coatings can be caused by improper application parameters.

**Rough substrates.** Paint films cannot level rough or uneven substrates. A primer with a rough surface will cause roughness in the topcoat.
Orange peel can be prevented by taking measures to ensure that the paint film flows out satisfactorily. These steps can include:

**Prevent dry spray.** Atomizing air pressure should not be excessive. Solvents should not evaporate too fast. The distance between gun and target should be monitored. Spray procedures should be proper.

**Atomize paint properly.** Atomizing pressure and paint viscosity should be monitored closely. To rule out cold paint (as a cause of high viscosity) and poor atomization, bring paints inside at least 24 to 36 hours before they are to be applied.

**Monitor paint film thickness.** A sufficient film build is necessary to ensure good paint flowout. Film thickness should be monitored frequently.

**Check surface smoothness.** To rule out surface smoothness as a cause of orange peel, the smoothness of the substrate should be verified before painting begins. Primer smoothness can be achieved by proper sanding.

**Runs, Sags and Curtains**

**Definition**

Paint applied on vertical surfaces may flow downward in various amounts before
the curing process hardens the film and stops the flow. All such downward flows are termed runs or sags; the lower portion of extended runs and sags may resemble scalloped lower edges of some styles of drapes and curtains.

**Causes**

The causes of runs, sags and curtains are almost always either applying a coating too thick or too wet. Causes of applying a coating too thick can include:

**Dirty gun.** A dirty gun, especially clogged air passages in the tip, can distort the normal spray pattern and make it apply heavily in some areas. Immersing a spray gun completely into a container of solvent for cleaning can cause this situation. If the entire gun is put into solvent, the dirty solvent will be forced into the gun air passages. Paint-laden solvent can dry in the air passages, leaving behind paint solids that will clog them or reduce their operating effectiveness.

**Poor operator technique.** Poor operator technique in painting complex parts may contribute to excessive application in certain areas of a part.

The causes of applying a coating too wet can be due to the following:

**Gun too close to workpiece.** If the spray gun is too close to the part being painted, an insufficient “flight time” for the atomized paint will leave excessive solvent in the paint when arriving at the part surface.

**Excessive solvent.** Adding excessive solvent to a coating will allow too much solvent to remain in the newly deposited paint.

**Insufficient air pressure.** An insufficient air pressure will atomize poorly, leaving large airborne paint particles, from which solvent evaporates poorly.

**Inadequate flash time.** An inadequate flash time between coats of paint applied wet-on-wet can leave a coating excessively wet. The problem of inadequate flash time often is encountered near the end of each month when line speed tends to be increased to get products out on time.

**Cold parts.** Applying paint to cold pre-primed parts may slow solvent evaporation enough to cause a wetness problem. This problem can result when parts are stored in an unheated warehouse and not taken in to warm long enough before being topcoated.

**Prevention**

Steps to take to prevent runs, sags and curtains can include:

**Dirty gun.** A spray gun should be cleaned properly. It should never be totally immersed in solvent; only the spray tip should be cleaned in this fashion. Leave the air on slightly when cleaning to prevent paint and solvent from entering the air passages. The gun should be checked regularly to prevent defective spray patterns caused by plugged air passages.
Defects in Applied Liquid Coatings

Poor operator technique. Operators should be trained to develop efficient spray procedures. They should periodically check the film thickness at different areas of a part to make sure they are not applying paint too thick in spots.

Gun too close to the workpiece. By moving the gun farther from the workpiece, the droplet travel time increases, allowing additional time for solvent evaporation, reducing the possibility of wet paint and the resultant runs and sags.

Excess solvent. If excess solvent has been added, a correction should be made. In some cases, particularly in cold weather, a fast evaporating solvent blend should be used. This will increase solvent loss during application so the applied paint is less wet.

Insufficient air pressure. A slight increase in air pressure will improve atomization and increase the surface area of the droplets. This will improve solvent evaporation and contribute toward a slightly drier paint.

Inadequate flash time. When applying coatings wet-on-wet, sufficient flash time must be allowed after each application. Otherwise, solvent can be trapped under the second coating, producing excessive wetness.

Cold parts. To prevent cold parts from slowing solvent evaporation and increasing wetness, the parts should always be brought to room temperature before they are painted. Parts that go through a washer will be warmed in the process, but occasionally parts that have already been primed are repainted or topcoated. If these parts are stored in an unheated warehouse, they should be brought to room temperature before being hung on the line to be topcoated. A good practice is to require that parts be delivered to the paint area at least 24 hours before being painted.

Paint Adhesion Loss

Definition

Adhesion loss is the premature separation of a paint film from a substrate.

Causes

The causes of paint adhesion loss can be due to one of the following:

Contaminants under the applied paint. The loss of large or small areas of paint due to poor adhesion is caused almost 95% of the time from contamination under the paint. This may be oil, grease, sanding residues, water or other contaminants.

Excessive bake time or oven temperatures on primers (and auxiliary coats). This may render the primer (or other auxiliary coats so thoroughly cross-linked that solvents in the next paint layer cannot microetch the surface to attain good adhesion.
Paints that differ widely in polarity. When an applied paint film differs substantially in polarity from the next applied paint, adhesion of the second coating may fail. Paints with widely differing polarities tend to repel each other.

Condensed moisture. High humidity in the paint shop may form condensation on parts to be painted, especially on cold parts. Applying paint over the moisture can cause fine blisters and even large scale adhesion loss.

**Prevention**

To prevent adhesion loss, the following steps should be taken:

**Clean parts thoroughly before painting.** All washer stages should be monitored regularly to ensure that bath temperature, concentration, pH, etc. are within specifications. Periodic tests should be conducted on cleaned parts to ensure that all soils have been removed.

**Maintain correct bake parameters.** Maintaining correct bake cycles and oven temperatures can prevent over-baking a coating, enabling the next applied paint to microetch the coating for a proper adhesion bite. If a previous coating should be over baked, a light scuff sanding may be beneficial to provide an anchor pattern for the next layer of paint. Sanding will cut through the hard outer glaze on the existing paint layer and allow solvents in the topcoat to “bite” into the previous paint layer.

**Maintain similar polarities for applied paints.** Sealer coats of intermediate polarity must be used between paints that have widely differing polarities. In this way the adhesion of primer to sealer and sealer to topcoat will be good.

**Condensed moisture.** Making sure that cold parts are warmed before they are painted can help prevent moisture from forming on parts when humidity is high, as is often the case around the pretreatment and paint area.

**Soft Paint Films**

**Definition**

Soft paint films are deposited coatings cured to a hardness below a designated specification. Soft paint films are easily marred (readily penetrated with a fingernail) and will have inadequate solvent resistance. When parts are stacked, parts with soft paint may “block” or stick together; they may also stick to or rub off onto paper and cardboard packaging materials. Another term for this blocking or sticking together is “printing.”
Causes

The causes of soft paint films may be due to the following:

**Low oven temperature.** A faulty oven temperature indicator system may result in oven temperatures below those required. Inadequate cure may be taking place without any indication that the oven temperature is incorrect.

**Low oven air makeup.** Insufficient fresh air makeup in the oven may retard the extent to which oxygen molecules react with paints that cure by oxidative cross-linking. Low air turnover may keep paint from developing full hardness by not allowing the removal of sufficient quantities of solvent during the bake cycle.

**Contaminant softening agents.** Solventborne paint will usually dissolve minor amounts of substrate wax, oil and grease and readily absorb moderate amounts of oil from compressed air. However, if significant amounts are incorporated into the paint film, the oil and grease can act as flexibilizers or softening agents.

**Excessive paint storage time.** Paint that has exceeded its shelf life may not cure properly. This is especially true with some high-solids coatings, which have a shelf life considerably less than low-solids paints. High-solids paints contain small, reactive molecules, so shelf life inevitably is short. When a paint exceeds its shelf life, cross-linking in the coating progresses so far that not enough cross-linkability remains to harden the paint fully when it is cured on the parts.

**Excessive retarder solvent.** Excess retarder solvent can prevent a paint from achieving normal hardness levels.

**Excessive film builds.** Excessive film builds may not permit full curing during the normal cure cycle.

**Insufficient cure time.** Too brief a cure time at a given temperature may leave the paint soft. This sometimes occurs when plants increase the line speed to meet production schedules without raising the oven temperature.

Prevention

Soft paint may be prevented by taking the following steps:

**Low oven temperature.** Oven temperature gauges and control systems should be checked periodically to ensure that the indicated oven temperature is true.

**Low oven air makeup.** Oven air makeup should be maintained at specified levels to be certain that sufficient oxygen is being supplied for oxidative cross-linking. Oven air turnover must be high enough to remove evaporated solvent.

**Contaminant softening agents.** Wax, oil and grease should be kept off parts to be painted. Compressed air should be checked for oil content.

**Excessive paint storage time.** Paint should not be stored beyond that recommended by the coating manufacturer.

**Excessive retarder solvent.** When retarder solvents are added to improve flowout
or gloss, extreme care must be exercised to avoid soft paint. Retarders should be added in small increments.

**Excessive film builds.** Operator care must be taken to avoid excessively thick paint films, which will not cure satisfactorily during normal oven cycles. If thick coatings are needed, the oven cycle should be increased.

**Insufficient cure time.** If the conveyor line speed must be increased, thus decreasing time in the oven, then oven temperature must be increased. Operators should be made aware of the relation between oven time and temperature. The paint manufacturer can supply time-temperature curves to allow correct temperature compensation for cure time variations.

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**Solvent Pops, Boils and Pinholes**

**Definition**

Solvent pops, boils and pinholes are tiny craters on the surface of paint films. They are small versions of bubbles and craters.

**Causes**

These defects are basically caused by overly rapid solvent loss from the wet paint. Solvent may escape in small “bursts” from paint film that has partially dried. The paint may be unable to flow back together to hide the escape ports, leaving tiny craters. The causes are basically the same as for bubbles and craters, only to a lesser degree. Additional causes for solvent pops, boils and pinholes include:

**Pigment clusters.** Insufficiently agitated paint may form pigment clusters that can trap solvent, delaying evaporation and forming solvent pops, boils and pinholes.

**Surface roughness.** Some types of surface roughness can act as nucleation sites for vapor bubble formation.

**High solvent evaporation rates.** High solvent evaporation rates can exaggerate solvent pops, boils and pinholes.

**Low solvent evaporation rates.** This can slow solvent evaporation during flash periods, leaving an excess amount of solvent to evaporate in the oven.

**Drafts.** Strong drafts can sometimes speed solvent evaporation to the point where solvent pops, boils and pinholes can occur.

**High oven entry temperatures.** Sudden exposure to a high heat at the oven entry can heat the paint film too rapidly, causing solvent pops, boils and pinholes.

**Bell-trapped air.** This is identical to solvent popping and is caused by tiny nicks
in the circumferential edge of turbine-driven bells. Atomization at the nicks can be inefficient and form large atomized particles that contain more solvent than the remainder of the efficiently atomized particles.

**Prevention**

Solvent pops, boils and pinholes can be prevented by taking the following precautions:

**Pigment clusters.** Efficient agitation will prevent the forming of pigment clusters. Filtering the paint will remove the non-redispersible pigment clusters.

**Surface roughness.** If compatible with the product design, the problem-causing surface roughness should be eliminated by a smoothening step in the manufacturing process.

**High and low solvent evaporation rates.** Solvent evaporation rates can be controlled by using only solvents recommended by the paint manufacturer. Extra flash time is beneficial for slow evaporating solvents.

**Drafts.** Direct impingement of blower-driven air onto freshly painted parts should be avoided.

**High oven entry temperatures.** The problem can sometimes be corrected by zoning the oven. This permits somewhat low temperatures at the oven entry to warm the part gradually and avoid overly rapid solvent evaporation. Subsequent zones are set increasingly warm to cure the paint fully.

**Bell-trapped air.** This can be eliminated by replacing bells that have nicks in their circumferential edges.

**Solvent Wash**

**Definition**

"Solvent wash" is the term used to describe paint voids or areas with thin paint due to solvent condensation.

**Causes**

Solvent wash is caused by excessive solvent evaporation from a painted part in the entry area of an oven and the condensation of this solvent on cool areas of the part. The solvent condensation can wash away either some or all of the paint where the condensation occurs. Solvent wash is most likely to happen on parts with paint applied extremely wet (solvent rich). Flowcoating and dip coating are especially
prone to solvent wash because of the high solvent content of these coatings. Solvent wash rarely occurs with spray or rotary application of coatings.

**Prevention**

If paint must be applied extremely wet, as in flowcoating and dip coating, sufficient flash time must be allowed for extensive solvent evaporation before entry into an oven.
Chapter 21

Paint-Related Testing

Various paint-related quality tests have been devised over the years. Most are aimed at verifying the integrity of a particular property of the paint or finish. The tests can be grouped into three basic categories:
- Tests of paint “in the bulk”
- Tests of paint application equipment
- Tests of the applied paint film

It is important that the evaluator know the correct evaluation system to rate and compare each test. Pictorial standards can be particularly helpful. ASTM descriptions include explanations of the preferred rating methods for most tests.

Tests of Paint “in the Bulk”

Paint in the bulk is often tested to determine:
- Weight per gallon
- Viscosity
- Weight percent solids/weight percent volatile organic compound
- Conductivity

**Weight per gallon.** Special metal containers holding a precise volume are used for this measurement. One such cup holds exactly 83.05 cc at 77°F. The weight of paint that fills the container, expressed in grams, is equal to the pounds per 10 U.S. gallons of the paint.

**Viscosity.** Viscosity is the ratio of the shearing stress and the rate of shear of a Newtonian liquid. Shear (in terms of liquids) is an applied force that disturbs a liquid at rest. In a Newtonian liquid the rate of shear is proportional to the shearing stress. In a non-Newtonian liquid the rate of shear is not proportional to the shearing stress. To explain viscosity in terms of shear and Newtonian/non-Newtonian liquids is complex and difficult to explain briefly.
For the purposes of this book, viscosity can be defined in simple nonscientific terms as a liquid’s “flowability.” A paint with a high viscosity has a poor flowability. (It is thick.) A paint with a low viscosity has a high flowability. (It is thin.)

Various instruments are available for measuring true viscosity, but they are used only by paint formulators in a lab. A simple, fast system has been devised for measuring paint flowability (viscosity). The system involves timing the rate of flow of a paint through a hole of precise radius. The device is referred to as a viscosity cup. It is a small metal cup with a precision hole at the bottom. The test consists of filling the cup and timing with a stopwatch the number of seconds for paint to drain in an unbroken flow from the cup. Names of some commonly used viscosity cups are Shell, Norcross, Zahn, Ford, Sears and Fisher. Figure 21-1 shows a Zahn cup. Table 21-1 provides a means of converting viscosity “seconds” from various cups to centipoise viscosity units.

![Zahn Viscosity Cup](image)

Figure 21-1. Zahn Viscosity Cup

Paint is normally purchased at higher-than-use viscosity. Solvent is added to reduce the paint to the correct application viscosity. Since temperature has a large effect on viscosity, plant paint personnel make the final adjustment to viscosity just prior to application.

**Weight percent solids/weight percent volatile organic compounds.** For an organic solventborne paint, the sum of the percent solids and the percent VOC will be 100, so finding one of these values readily provides the other. The test involves weighing a wet sample of paint, then evaporating the volatiles and reweighing the remaining solids. The test can be done simply in this fashion:

Fill a 5-milliliter or 10-milliliter syringe with paint and weigh carefully. Into a small preweighed beaker or disposable aluminum cup, deliver roughly 4 milliliters
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Table 21-1. Viscosity Conversion
of paint. Then again carefully weigh the syringe to determine the weight of wet paint in the beaker or cup. Bake the sample for 1 hour at 235°F. Then let it cool and reweigh the beaker plus the sample to find the dry solids weight. The percent solids and percent VOC by weight can be found as follows:

1. Percent solids = \[
\frac{\text{weight of dry paint}}{\text{weight of wet paint}} \times 100
\]

2. Percent VOC = 100 minus the percent solids

The procedure for waterborne paints requires that the percentage of water be found by using gas-liquid chromatography, which not readily available in most plants, or be determined by the “Karl Fisher” method, which is complex and virtually never attempted by painting personnel. It is not given here for that reason.

Determining volume percent solids requires weighing an unpainted disposable small part both in air and in water and reweighing the part in air and in water after it has been coated and cured. It is not commonly part of plant paint testing. The details of the test can be found in ASTM D-2697-73.

Conductivity, the conductivity of paint can be measured as resistance with an ohmmeter adapted with wide-surface terminals to ensure test consistency. Conductivity is the reciprocal of resistance; the higher the resistance, the lower the conductivity.

Some coatings need to be highly conductive, such as coatings to provide electromagnetic/radio frequency interference shielding. Coatings to be applied electrostatically need to have a low conductivity (high resistance) to hold the electrical charge. Values of 1 to 5 megohms resistance are normal. High-resistance paint can be used for automatic application, which can use high voltages. Manual application is most often done with paint having about 1 to 2 megohms resistance. Too much conductivity causes Faraday cage problems; too much resistivity minimizes the electrostatic advantages of wraparound and high transfer efficiency.

**Tests of Paint Application Equipment**

Various tests can be conducted on paint application equipment, depending on the type of equipment being used. Three tests that can be conducted are:

- Checking for an electrical ground
- Measuring electrostatic voltage
- Determining transfer efficiency (TE)

**Checking for an electrical ground.** Good electrical ground connections in electrostatic painting ensure maximum electrostatic attraction of paint to the
product and prevent spark-producing charges from building on the product. The electrical path to ground goes from the product to a support such as a hook or hanger to the conveyor trolley to the conveyor channel to the grounded building metal framework. A poor connection at any of these junctions can constitute a poor ground.

A test for an electrical ground can be made with an ohmmeter or a “decreased ground detector.” In both cases one terminal is attached to the product to be painted, and the other to a good ground, such as the conveyor I-beam. If an ohmmeter reads 1 ohm or less, the part is grounded properly. The “decreased ground detector” can be made to give either an audible or visual alarm (or both) if grounding is poor.

The usual causes of poor grounds are accumulated paint on hooks and hangers or dirty conveyor wheels and channels.

Measuring electrostatic voltage. Most electrical control panels will indicate the voltage of the electrostatic power supply. It is a good idea to check the voltage at the application device occasionally to ensure that sufficient voltage is reaching the applicator for good electrostatic charging. Voltage testers are available for this purpose. Instructions should be followed carefully, and all safety precautions observed.

- **Determining transfer efficiency (TE).** TE is a measure of the amount of paint applied to a part in comparison with the total amount of paint used. TE can be determined if the percent solids (by weight) of the paint is known by:
  - weighing the paint container before and after use in painting a set number of parts (A).
  - weighing the parts before painting, then weighing again after painting and curing is complete (B).
  - multiplying B by 100 and dividing by the percent solids (C).
  - multiplying C by 100 and dividing by A.

TE also can be determined by measuring the dry-film thickness (DFT) (in mils), the area covered (in sq ft), acquiring the percent volume paint solids from the coating supplier, measuring the volume of coating used and putting the figures into the following formula:

$$\% \text{ TE} = \frac{\text{sq. ft. painted} \times \text{mils DFT}}{\% \text{ vol. solids} \times \text{gal. used} \times 0.1604}$$

The 0.1604 is simply a unit conversion factor.

### Tests of Applied Paint Film

Numerous tests can be performed on applied paint films. Among the most common are:
It is important to remember that a number of coatings, especially air-dry alkyds, will continue to cure for as long as a week or two after the initial apparent cure. For this reason a conditioning period after curing must be allowed before accurate testing can be done on the dry film. This is especially true for tests such as hardness and corrosion resistance. A conditioning time of 24 to 72 hours before a testing is a common practice for durability and adhesion tests. However, tests of film thickness, gloss, color match and any tests not related to the extent of cure can be done immediately. In most cases the test results will improve after the conditioning period. If “early” tests show satisfactory performance, parts that have gone through the requisite conditioning period need not be re-tested.

**Wet-Film Thickness**

The most commonly used wet-film thickness gauge resembles a comb with two outer teeth of equal length and about 10 teeth in between of varying lengths. When the gauge is placed into the wet film and then removed, the marking on the last tooth to be wetted by the paint gives a readout of the wet film thickness. Because the gauge leaves a visible imprint in the wet paint, it is a destructive test.

The thickness of a wet paint film is seldom of interest. Some times knowing the wet-film thickness is helpful, such as when painters are being trained, to satisfy specifications, or when setting up automatic application equipment.

**Dry-Film Thickness**

The dry-film thickness of coatings on magnetically responsive ferrous substrates (containing iron) are often measured with magnetic “pull-off gauges.” These devices have a magnet suspended by a spring inside a nonmagnetic body (usually aluminum). When touched to the painted surface, the magnet attracts the metal through the paint film. The spring will be stretched whenever the body is pulled vertically away from the surface. The magnetic attraction to the steel is reduced as the coating thickness increases. The thicker the paint, the weaker the magnetic attraction. Thus the spring is stretched less when the gauge is pulled away from a thick film than from a thin paint layer. The two types of magnetic pull-off gauges are “pencil” and “banana” (roll-off).
A pencil gauge, as shown in Figure 21-2, has a magnetic head attached to a spring and a pointer. Gradual manual pull-off of the gauge away from the surface gives a reading of paint film thickness with an accuracy of plus or minus 15%. One of the easiest-to-use pencil gauges looks and operates similar to a hypodermic syringe. This gives a lasting readout value. With many pencil gauges, as soon as the gauge is pulled away from the surface, the reading disappears. If these instruments are not operated vertically, the manufacturers state that accuracy is reduced, but can be improved by plotting a correction curve for each angle away from true vertical. If most readings taken are not done vertically, a Tinsley type 7000 gauge may be preferable. It contains a meter-like scale readout with a balanced pointer that is unaffected by its angular orientation. The type 7000 gives accuracies of ±10%.

A banana gauge, as shown in Figure 21-3, has improved accuracy. Rotating the wheel slowly pulls a magnetic head away from the surface being measured. When the magnet breaks contact, both an audible “click” and an indicator inform the tester to cease rotating the pull-off wheel. At this point the calibrations on the wheel allow the film thickness to be read directly in mils or microns. The cost of these devices is approximately double that of the pencil gauges. All gauges of this type provide a lasting readout value, unlike some pencil gauges that lose the thickness reading when the magnet head releases from the surface. Roll-off gauges can also be recalibrated as necessary.
Both magnetic devices are portable, easy to use and low in cost. They do not damage the coating and do not require batteries. However, they work only on iron and steel painted with nonconductive coatings. The magnet tip should be visually inspected periodically for wear, steel particles and other contaminants that could disturb the readings. Exposure of a magnetic gauge to a strong electrical or magnetic field can alter its strength and change the calibration. A number of manufacturers will recalibrate the device for a service fee. This should be done if it does not give correct readings when checked against a known film-thickness standard.

Dry-film thickness on nonmagnetic metals such as zinc or aluminum can be measured using eddy current detectors. These measure film thickness based on the relative strength of eddy currents in the metal induced by a varying magnetic field in a conducting coil. Differences in the current flow (because it is alternating current) within the coil are related to the film thickness separating the coil and the metal under the paint film. These compact devices are normally accurate to ±5%. Battery-operated units can be hand-held. Their accuracy, size and ease of operation have made them popular. They must be calibrated for the particular type of metal substrate of the part being checked.

If extreme accuracy is needed, film thickness can be measured with beta ray back-scattering devices. They emit electrons (that years ago were called beta rays), and then the amount of deflected rays are measured. These instruments provide extremely accurate values as long as an appreciable difference exists between the nature of the substrate and the paint. They work well measuring paint thicknesses on metals, wood, paper, cardboard, etc. and on many (but not all) plastics. These devices are quite costly and require careful and time-consuming calibration.

Measuring paint film thickness on plastic parts by beta ray backscatter can often present difficulties because the paint is structurally similar to the substrate. Nor will pull-off, roll-off gauges or eddy current detectors function on nonmetallic
parts. Some of the alternative methods used for measuring dry-film thicknesses on plastic include:

- Measuring the plastic thickness before and after painting, using a micrometer or other means
- Measuring the thickness of a piece of tape placed on the plastic (before and after painting)
- Using a Tooke gauge to look into a short V-shaped groove cut through the paint into the substrate. When the magnifying glass supplied with this instrument is put over the groove, internal markings allow a direct thickness readout of the paint film.

Since the last two tests are destructive, they are normally run on scrap parts or on nonappearance areas.

**Adhesion/Flexibility (Bend, Impact)**

Paint film adhesion/flexibility can be tested in several ways. One way is to put a painted panel through various types of bends. Another way is to drop objects onto a painted panel.

In the **bend** test, a panel painted on one side can be folded back onto itself (with the painted surface on the inside of the fold) to test for compressive paint adhesion/flexibility film stresses. A painted panel can be folded in the same way with the painted surface on the outside of the bend to test for tensile (stretch) adhesion/flexibility stresses. This type of a bend is termed “0T,” pronounced “zero-T.” The “T” stands for thickness. A panel bent back onto itself has a 0T bend; a panel bent back over another panel of the same thickness has a 1T bend; the “1T” stands for one thickness. Similarly, a panel bent back over two panels of the same thickness has a 2T bend, and so on. It follows that the tighter the bend radius, the greater the severity of the compressive and tensile stresses on the paint film adhesion/flexibility.

Painted test panels may also be folded around cylindrical rods of various diameters to test for adhesion/flexibility compressive and tensile stresses. Similarly, painted panels may be tested for adhesion/flexibility by folding them around cone-shaped rods. These tests are known as “cylindrical mandrel” and “conical mandrel” bend tests, respectively.

Tests of paint film adhesion/flexibility by **dropping objects** are conducted by dropping steel balls or rounded weights onto both the painted side of a test panel and the unpainted side. The test weight may be dropped from various specified measured distances. Striking the painted side of a panel is referred to as a “direct impact test”; striking the unpainted side of a panel is termed a “reverse impact test.” In direct impact tests, the concave-dented painted surface is studied. In reverse impact tests, the convex-protruded painted surface is examined. Overly
brittle paint will lose adhesion in these types of tests.

Various shapes are used but all such tests are commonly termed “falling ball impact” tests.

### Adhesion (Tape)

The adhesion of a paint film to a surface can also be measured by applying a piece of tape to the paint film and pulling the tape off the paint. A 3-inch-long piece of 1-inch-wide transparent fiber-reinforced plastic tape is pressed down onto an area free of blemishes or other surface imperfections. The tape is smoothed into place with a finger, then rubbed tightly to the surface with an eraser on the end of a pencil. A dark color under the tape indicates that the tape has been affixed firmly. One end of the tape is grasped and pulled steadily and quickly (but not jerked) back on itself as close to the plane of the tape as possible. ASTM D-3359 is considered to be the standard tape adhesion test, although hundreds of variations of this test are employed. The ease of the test is an attractive feature. ASTM provides a rating scale to evaluate the results. The results may vary if the tape test is performed immediately after the paint film is cured instead of waiting until after a conditioning period.

The test may be performed directly on an unaltered paint film or on a paint film that has been scored (scratched) with an “X.” The paint may also be cross-hatched with multiple score lines in different fashions and then tape-tested. Sometimes these test methods may be performed after the panel has been subjected to varying temperature, humidity or salt spray exposures. Occasionally a specification will call for a tape adhesion test to be performed on a painted panel that has been immersed for an hour in deionized water.

As long as a test is conducted identically each time, the correctness of the method is of secondary importance. It is informative, however, to read the tape test procedure in ASTM D-3359. ASTM excels at stipulating how tests are to be executed. Until one has read the ASTM documents, it is hard to imagine how much detail can be specified to perform a test as straightforward as this one. Following ASTM guidelines for a test helps ensure that the same procedure is performed identically for each test. In this way the results obtained are accurate and repeatable. ASTM instructions are also helpful in showing how to convert observed test results into meaningful numerical ratings for comparative evaluations.

### Hardness

Although sophisticated paint film hardness testing methods are available, the ASTM D-3363 pencil hardness test is simple and convenient. Hand-held pencils
with leads of varying hardness are pushed (lead first) at a 45-degree angle against the paint film to determine the hardness. The pencils are not sharpened to a point; the full round of exposed lead is squared off. The edge of the lead is then pushed against the paint film at the specified angle. The amount of force on the pencil must be enough to cut or scratch into the film, or to break off the edge of the pencil lead. Check closely for marks in the paint film. Begin testing with the hardest lead, then decrease hardness until the hardest pencil that will not mar the paint is found. Some plants measure both “gouge hardness” and “scratch hardness,” but most look only for “mar hardness” of any kind.

Paint film pencil hardness is rated on a scale of numbers and letters from soft to hard as follows: 6B, 5B, 4B, 3B, 2B, B, HB, F, H, 2H, 3H, 4H, 5H, 6H. The pencil hardness test is crude, but quick and adequate for the purpose.

A hardness test is often a measure of the extent of cure of a paint film; under-cured films will be soft, and over-cured films will be excessively hard. Normally a permissible range of hardness rather than a single hardness value is written into a coating specification, such as “2H minimum to 4H maximum film hardness shall be required.”

Chemical resistance

In chemical resistance tests, various chemicals are applied to paint films, followed by examination of the film for harmful effects. Popular chemicals for such tests include acids, alkali and solvent.

Stain resistance

In stain resistance tests various materials are applied to paint films, followed by washing and examining for stains. Vinegar, catsup, mustard, iodine, bleach and detergent are often used. The appliance industry is vitally interested in having a painted finish resist staining and discoloration from common foods and household products.

Extent of Cure

The hardness test is one measure of how well a paint film is cured. A much preferred one is the “solvent rub” test, which measures the film’s resistance to dissolution in whatever solvent is deemed to be most appropriate. In this procedure the finish is tested for color removal after a number of manual double rubs with a cloth or paper towel saturated with the specified solvent. For example, it might be
specified by a purchaser that if no color is evidenced on the cloth after 50 double finger rubs with acetone or methyl isobutyl ketone, the paint film is considered to be cured adequately.

**Water Immersion**

Moist and wet conditions can bring out poor adhesion and/or a tendency to blister formation. Water can be a highly reactive chemical. It will penetrate most paint films readily and can produce undesirable effects unless the proper paint is correctly applied at the necessary thickness onto a correctly prepared surface. The tendency of a film to form blisters can be rapidly measured by the simple expedient of soaking the part in deionized water. This is a more strenuous test for blister formation than soaking in salt water because the osmotic pressure to lift the paint film is greater with deionized water.

**Humidity Resistance**

In regular humidity testing the parts are hung vertically in a high relative humidity at around 100°F for a specified number of hours. Steam is used to supply the moisture.
Figure 21-5. Painted Panels Exposed to a Condensing Humidity Test
With the "condensing humidity test" painted panels are set at about a 30-degree angle from horizontal over a reservoir of warm water, as shown in Figure 21-4. The painted side of the panels faces the water; the reverse side of the panels is exposed to ambient room temperature. Water vapor condenses on the warm, moist side of the panels and drains down into the water reservoir. The heat of condensation and the continuous draining of the very pure water (actually distilled by the test process) constitute a severe test of the paint adhesion and resistance to moisture. Figure 21-5 shows paint film test panel blisters produced in a condensing humidity chamber. Condensing humidity can be done for as long as desired, but the maximum time is generally about 24 hours. In addition to visual examination after humidity testing, the panels can be subjected to other tests such as tape adhesion.

**Accelerated Weathering**

Various types of testing cabinets have been devised for accelerated weathering tests. Figure 21-6 shows one such accelerated weathering test cabinet. The threads of commonality among them are heated moisture and provisions for spraying with salt solutions. Accelerated weathering tests can have two purposes:

![Figure 21-6. Accelerated Weathering Test Cabinet](image-url)
• comparing the performance of different coatings
• determining how a coating will perform in the field

Comparing the performance of different coatings. Paints are often checked for resistance to salt spray corrosion to determine if they are better than a currently used coating, or to determine the best paint from among several possible candidates. Test panels may be exposed to dilute (5 to 10%) sodium chloride spray mist at 100°F for an appropriate number of hours. Two types of failure may be noted. “Face rust” is the appearance of rust on the surface of the part or panel where the coating seems continuous. “Creepback” is the spread of rust and subsequent loss of paint away from a line scribed through the paint into the underlying metal. Tests are usually conducted according to ASTM B-117 or B-287.

However, some tests may be misleading. For example, salt spray tests on painted zinc and galvanized parts often appear worse than on painted steel parts, yet the painted zinc provides far superior corrosion resistance in field service. For this reason it is recommended that salt spray tests not be conducted on painted zinc.

The relative performance characteristics of paints can be ascertained from these tests. A paint showing failure at 100 hours of salt spray testing is probably not as durable as one that does not fail until after 200 hours of testing.

Accelerated testing can usually determine the best performing paint among a group of potential candidates. The most durable paint in a group can be determined with fairly high certainty by testing all the candidates under the same conditions. If the test parameters are selected carefully, the paint that performs best in testing would be expected to give the highest performance in the field under normal usage conditions. This has been found to be true at least 98% of the time. Only in rare instances has it been found that the results of accelerated testing are reversed in actual service. If the wrong test is selected, the differences among the candidates may not be discovered, and all will exhibit the same test durability.

Painted parts may need to meet a specification of 96 hours in a given accelerated test condition, or 500 hours or in some cases even 1000 to 1200 hours under specified test conditions.

Determining in-house how a coating will perform in the field. The warm salt spray in these cabinets severely tests the integrity of a paint film by speeding corrosion rates. Theoretically the duration of a test can relate to service time in the field.

Accelerated weathering tests may run from 1 hour to over 2000 hours to simulate many months or years of service exposure. The question is frequently raised, “How many years outdoor exposure is represented by each 24 hours of salt spray testing?” No reliably accurate answer to this question is available, unfortunately.

In order to make accelerated tests as close to service life conditions as possible, evaluation groups have run tests under an extreme variety of conditions of
temperature, humidity and salt spray concentration both with and without added corrosive agents such as copper acetate, acetic acid, etc. In some cases ultraviolet light is added during simulated exposure tests.

Whatever the test conditions, as long as they are thoughtfully selected to simulate service exposure as closely as possible and properly evaluated, they will give at least some indication of field performance.

Cyclic accelerated weathering tests have been developed that relate more closely to field conditions than continuous salt spray tests. Thus, a 500-hour cycle test that resembles a product's actual end-use conditions of varying thermal and chemical exposure conditions may be more realistic than just 500 continuous hours at an unchanging temperature and humidity. A typical cycle test may involve 15 minutes soak in 5% neutral sodium chloride solution, 1 hour at room temperature, 20 hours at 140°F with 85% minimum relative humidity and several hours at 30°F. This pattern may be repeated until a specified number of cycles has been completed.

In cyclic testing, the tester's imagination is the only limit on what can be devised. It is convenient if each cycle is 24 hours long because it fits the work schedule of test personnel who will normally be at work for only one shift each day.

Panels may be tested as painted, they may be scribed with lines or the paint may be subjected to stone bombardment by a gravelometer. The test results may be determined by visual examination such as the amount of paint loss back from a scribe line; or tape testing may be done to determine how much adhesion will be lost after these simulated tests.

**Gloss**

Gloss is a measure of the amount of light reflected from a surface. A surface that reflects all of the light has a gloss of 100. One that reflects no light has a gloss of zero. The gloss number is not stated as a percent, yet the number represents the percent of light reflected from a surface.

Instruments that measure gloss (gloss meters) send a beam of light (incident light) at a particular angle from the vertical directed at the surface to be measured. The instrument measures the amount of light reflected at the same angle. The angle of incident and reflected light is usually specified at 30, 45 or 60 degrees. The smaller the angle (to the vertical), the more light will be reflected and the higher will be the gloss reading. This is why it is important that the angle of incident light be given for each gloss reading. “The gloss is 88 at a 60-degree angle.” Smooth surfaces reflect more incident light than do rough surfaces. The amount of reflected light is independent of the color of the surface.

To maintain accuracy, a gloss meter must be calibrated frequently against gloss standards in a range near to that being measured. Suitable standards should be
available when a gloss meter is purchased, and they should be kept with the instrument.

“Specular gloss” is the shininess or brilliance on highlighted areas of a part. “Sheen” refers to the specular gloss at very small angles of light incidence and reflection. “Brilliance” is the apparent strength of a color as perceived visually; it can be compared to loudness of sound.

**Distinction of Image**

Distinction of image (DOI) is the measure of how well a surface acts as a mirror. A “polished black glass standard” has a perfect DOI; it is a perfect mirror, perfectly reflecting every object. Some DOI instruments have a perfect rating of 100; at least one has a perfect rating of 20.

A surface with a perfect DOI will be perfectly smooth. So, in a sense, DOI is a measure of surface smoothness.

Gloss and DOI are often confused. Gloss is the measure of the ability of a
surface to reflect light. A surface that is not perfectly smooth may reflect all of the incident light. However, a surface not perfectly smooth cannot perfectly reflect an image. A surface with a high DOI is also high in gloss; but a surface with a high gloss may not be high in DOI.

For a painted surface to be high in DOI, the substrate must be smooth, and the paint film must be free of orange peel. Moderate orange peel will not detract much from gloss, but it will reduce DOI.

Instruments that measure DOI project an image onto a painted surface and detect the distortion that occurs when the image is reflected from the surface. Some DOI devices rely on visual evaluations, and these may be inconsistent. The evaluators rate a test panel based on the ability to see or not to see distortions in various images projected onto the surface under test. It has been shown that values thus obtained will not only fluctuate widely among evaluators, but significant variations are also perceived by the same person on the same panel if shown the panel at different times.

One DOI instrument, shown in Figure 21-7A, photographs the reflected image from the paint film being tested of the test grid in Figure 21-7B. The operator looks at the developed picture of the reflected image. The DOI is the number of the grid where the operator decides that the parallel lines in the picture just seem not to touch. It has the advantage of providing a permanent photographic record of DOI.

Distinction of reflected image (DORI) and the abbreviation “DI” are the same as DOI, which should be used rather than the variations to avoid confusion.

**Color Match**

Color does not have a real physical existence. It is a human sensation arising from the interaction of electromagnetic vibrations on the eyes as interpreted by the brain. Almost every one has seen various colors separated from each other by a prism, by rain drops to produce the rainbow or by a thin layer of oil floating on water. The separated colors include red, orange, yellow, green, blue, indigo and violet.

The “wavelength” of light is the tiny distance between corresponding consecutive points in the electromagnetic radiation. Wavelengths that humans can detect visually are in a small portion of the total electromagnetic spectrum. Beyond the longest visible wavelengths are the infrared waves that are associated with heat, and then the microwaves, radio and television broadcast waves. Out past the other end of the visibility range lie the short but high-energy waves such as ultraviolet light, gamma rays and X rays. Figure 21-8 gives a breakdown of various types of electromagnetic radiation and the associated wavelengths.

Wavelengths in the visible spectrum lie in the tiny region between 4000 and
7500 angstroms (1 angstrom equals $10^{-10}$ meter). The longer the wavelength, the lower the energy associated with it. Thus, the 7500-angstrom end of the visible spectrum, the red wavelengths, are lower in energy than the 4000-angstrom violet wavelength end. Between the red and blue lie orange, yellow, green and blue/indigo.

The color of an object depends on the wavelength(s) of light reflecting from the object. A white object reflects all visible wavelengths; a black object doesn’t reflect any visible wavelengths. An object with a particular color reflects the wavelength(s) required to make that color.

The sun radiates visible colors of all wavelengths. An object receiving sunlight will absorb the wavelengths of visible light that it does not reflect. A source of light deficient in some visible wavelengths, for example, fluorescent lighting, will cause an object to appear a different color than will sunlight. This is because sunlight and fluorescent light contain different visible wavelengths, which will cause an object’s reflected visible wavelengths to differ.

Paint pigments are able to separate the colors of light by absorbing some or all of the individual visible wavelengths present in the light source. Thus, a red pigment reflects red light and absorbs all the others. If several pigments of different colors are in a paint, the individual pigment colors cannot be perceived, but instead, a single color will be seen that is a blend of the combined pigment colors. Mixed white and black pigments will give a gray color; similarly, mixed blue and yellow pigments will yield a green color.

When a broad spectrum light such as daylight hits a pigment particle, in addition to selected absorption of some of the visible wavelengths, some absorption often occurs across the visible spectrum. This “muddies” the color. The most desirable pigments have less of the muddy overtones in the colors. Matching paints can be a problem because the exact shade of a coating depends on many factors,
such as pigment particle size and shape, spray pressure, target distance, booth humidity and film thickness.

Paint colors can be matched fairly well visually but can be matched precisely with an instrument. Color matching, whether visually or instrumentally, should be done under several light sources. The light sources may include reddish (sunset type) lighting, as well as a bluish (northern sky) lighting.

Two frequently used color measurement scales are the Munsell and the CIE (L, a, b) systems. Both use a “tristimulus” method. Tristimulous means that three different stimuli are used to determine a color. The Munsell system uses the terms hue, chroma and value. The particular shade of color (hue) is determined; the intensity of the hue is the chroma; the value scale varies gradually from pure white to pure black. The CIE scale uses a lightness, black-to-white L scale. In the “a” scale, positive values are increasingly red, and negative values more and more green. For the “b” scale, higher negative values are increasingly blue, and greater positive values become progressively more yellow.

### Which Tests to Run?

Tests selected for paint depend on many variables. Paint manufacturers run various tests to determine if the paint measures up to the specifications set by the end user. Finishers also conduct various tests, the exact tests are determined by such factors as:

- Plant size
- Plant location
- Part quantity
- Type of parts
- Indoor or outdoor service location of parts
- Size of parts
- Color of parts
- Application methods
- Normal service life of parts
- Cost of parts being coated

Finishers perform various tests on paint as the paint is received from the paint manufacturer. These incoming material inspection tests may include:

- Weight per gallon
- Percent weight solids
- Fineness of grind
- Color match to standard
- Gloss
- Hardness
- Viscosity
- Adhesion and flexibility
- Chemical and stain resistance
- Paint transfer efficiency

A volume percent solids test is seldom run because of its complexity. The only method available is described in ASTM D-2697.

Tests run by finishers for production control may include:

- General overall visual appearance
- Gloss
- Color match to standard
- Hardness
- Dry-film thickness
- Normal service life of parts
- Cost of parts being coated
- Application methods
- Adhesion and flexibility
- Chemical and stain resistance
- Paint transfer efficiency
In a majority of finishing plants, wet paint tests are not common practice. The exception, of course, is paint viscosity testing that is routinely done in nearly all wet painting operations. The majority of paint tests by finishers are run on panels or parts after the coating has been applied and cured.

Anyone involved in paint testing should study the ASTM book of standards. These standards are revised periodically, and new standards are written as tests are developed. ASTM publishes all of its standards yearly. Those related to paint testing are in Section 6.01.
Chapter 22

Stripping

In industrial painting, stripping is the term for removing unwanted cured paint film from a surface. The unwanted paint film may be on a conveyor hook, paint hanger, spray booth floor grating or similar equipment. Unwanted cured paint also may be on a finished product that needs to be stripped for refinishing. Painted rejects are often stripped and repainted because this is less costly than manufacturing a totally new product. Stripping is done also after paint films have undergone a life cycle, such as on commercial or military airplanes, ships, trains, buses, etc.

Painting equipment, such as hooks, hangers and floor grating, are stripped regularly for operating efficiency. For example, clean hooks and hangers can ensure a good ground for maximum electrostatic attraction. Clean floor gratings can optimize air flow and enhance painting operator safety.

Types of Stripping

Stripping of paint from industrial equipment and products is done using any of these basic methods:

- **Mechanical**
- **Solvent**
- **Blasting (media)**
- **Blasting (water)**
- **Chemical**
- **Burn-off ovens**
- **Molten salt baths**
- **Hot fluidized sand**

**Mechanical.** Mechanical stripping uses physical contact devices that abrade, cut or scrape. Manual techniques are labor-intensive and potentially hazardous. Hand tools employed include scrapers, sandpaper and wire brushes. These methods are crude and usually leave a poor surface finish. Manually operated power tools can expedite the process. If the paint is strongly bonded to the surface, manual methods are usually not effective in achieving complete removal.
Blasting (media). In blasting with media (tiny pellets such as sand), the media is hurled at high speed against a cured paint film. Each individual media particle abrades a tiny fragment of the paint film. Repeated bombardment by thousands of media particles gradually removes the paint film.

Various methods are used to project the media onto the surface, such as air pressure and a spinning wheel. The hurled media is almost always recovered and reused. A screening filter can separate the stripped paint fragments from the media.

Many different types of media are available, ranging from sand to particles of plastic. The hard types of media are used in stripping thick, tough-to-remove paint. Plastic media are used for “gentle” stripping and are often employed in aircraft repainting (see Figure 22-1) to strip individual coatings, such as a topcoat from a primer.

In one type of media blasting (termed cryogenic stripping), the product and paint film are immersed in liquid nitrogen (about -320°F) to embrittle the paint film. The product is removed from the super cold nitrogen and immediately blasted with media. The embrittled paint film usually can be removed readily with blasting. However, some paint films are resistant to this process.

Blasting (water). This type of stripping uses a high-pressure (3000 to 10,000 psi) stream of water to remove a paint film. It is used regularly in high-volume paint booths to strip paint from floor grates. Extreme caution is necessary to prevent human injury from the high-pressure water stream. Machines are always employed for this process that are designed to shroud the high-pressure water stream in order to protect the operator and workers in the vicinity.

Chemical. Many chemicals are available for stripping paint films. The chemicals are usually categorized according to whether they are heated aqueous solutions (hot strippers) or unheated organic solvents (cold strippers). Hot aqueous strippers may be acidic, but far more often are alkaline. Both hot types strip paint by destroying the bonds that hold the paint resin together.

Organic solvent strippers employ a single solvent or a blend of solvents to soften and dissolve paints.

Alkaline strippers contain strong concentrations of potassium hydroxide or sodium hydroxide and possibly high concentrations of trisodium phosphate. In the past some have contained phenols. Phenols are highly effective activators for reactive strippers, but the disposal of phenolic waste is restricted. The use of phenolic agents in strippers is now severely limited.

Heat is a valuable aid in alkaline stripping. The boiling point of concentrated hot strippers may allow temperatures of 225 to 235°F to be reached. Vigorous boiling action in hot tanks provides helpful bath agitation.

Hot alkaline stripping solutions can rapidly degrade many paint resins to the point that the paint is completely removed (or nearly so) in the stripping tank. For extremely adherent paints or durable resins some physical scraping or abrading
may be necessary.

Hot caustic chemicals cannot be used on zinc or aluminum because they react vigorously with these metals. The alkali will quickly dissolve such parts.

Acid strippers use nitric, sulfuric or phosphoric acids, either alone or in combination. Acidic strippers are seldom used because they tend to be corrosive and have other undesirable properties.

Hot stripping chemicals are consumed and need replenishment periodically. In time the hot stripping action will weaken and will require the accumulated paint sludge to be removed. At this time about half of the solution should be discarded and replaced with fresh solution makeup. Water loss should be replaced regularly.

A disadvantage of hot stripping tanks is that to be used on short notice, the tanks must be heated continuously. Another disadvantage is the danger to personnel from fumes and potential scalding. Condensation of water vapors can create a messy working environment.

Restrictions on land burial, liquid discharge and air emissions have placed limitations on chemical stripping. The spent stripper solution must be disposed of properly. The stripped-off paint forms a sludge that can be removed from the bath by filtering. The rest of the spent bath needs to be neutralized before discharge. Local restrictions may not allow draining to sewer.
Solvent. Certain solvents at ambient temperature have the capability of stripping paint films, eliminating the need for heated solvent. Ambient temperature solvent stripping is an excellent alternative method of stripping paint from aluminum, zinc and other metal parts that cannot tolerate hot caustic or stripping methods using intense heat. Solvent stripping is used either as a dip or spray, depending on production requirements.

Solvent strippers include highly aggressive oxygenated phenols, ketones, glycols and esters, as well as saturated or aromatic hydrocarbons. Many solvent stripping products have toxicity concerns. For example, phenols are highly corrosive and toxic; nonphenolic solvents are often toxic and flammable; halogenated hydrocarbons have toxicity/disposal concerns. Nonflammable halogenated solvents such as methylene chloride, trichloroethylene and 1,1,1-trichloroethane formerly were used indiscriminately before the age of toxic chemical regulation.

Solvent strippers remove paint either by dissolving or softening action. Lacquer films totally dissolve in solvent stripping. Other coating films, however, will swell, soften and wrinkle, greatly simplifying physical removal.

Vapors are a serious problem with solvent stripping. Some of the vapors are hazardous to the health of workers, especially if the workers remain in the presence of the odors for long periods. Other solvents have odors that workers find offensive. One way of containing solvent vapors in a stripping tank is to use a wax that floats on the surface of the solvent, forming a vapor seal. Another technique that is moderately effective as a vapor seal is to use water if the solvent has a high enough density to enable the water to float on the solvent. Some solvents, however, cannot tolerate water. For example, water added to halogenated hydrocarbons can form hydrochloric acid, which is highly corrosive to steel.

Paint removed in a solvent stripping tank accumulates on the bottom from which it can be periodically separated out. The remaining solvent is not reduced in stripping effectiveness.

One of the biggest problems with using solvent strippers is how to dispose of the solvent-rich paint sludge. Flammable solvents sometimes can be incinerated. Nonflammable halogenated solvent strippers cannot be disposed by burning. They form the corrosive irritant hydrogen chloride gas when exposed to flame. Stripped paint sludge containing either flammable or nonflammable solvent residues are seldom permitted at ground disposal sites.

The solvent in paint-stripping sludges and spent cleaning solvents can be reclaimed, often for direct reuse, by distillation. A number of solvent stills use replaceable plastic bags in which the solvent-free dry residues are collected for convenient and safe disposal. If no toxic substances are present, ground burial may be acceptable at some waste disposal sites.

The use of halogenated hydrocarbons for solvent strippers has declined because they cannot be burned and are no longer allowed in most disposal sites. Many plants have no place to get rid of halogenated solvents at a reasonable cost.
However, the increased use of distillation to recover solvents of all types has brought a mild return to using halogenated solvent paint strippers.

The cost of having a private disposal firm handle paint and solvent waste is frequently prohibitive. For small-quantity waste producers, however, contracting with an outside firm to perform waste management may be cost-advantageous. Companies of any size should look into the relative economics of such an approach to disposing of paint and solvent. A number of plants have been pleasantly surprised to find that it is less costly to use a disposal service company than to distill their own used solvent. In general, however, many plants have turned away from solvent stripping because of the disposal problems. With many powder coatings and with the newer high-solids and waterborne coatings, chemical stripping is slow and less than fully effective.

**Burn-off ovens.** Burn-off ovens are batch-type ovens that are designed to operate at about 1000°F. The high temperature burns the organic portion of the paint film, leaving an inorganic ash residue. The oven design includes various methods of eliminating the generated smoke.

Some burn-off ovens include an auxiliary unit for washing the ash residue from the stripped parts. Such a unit confines the ash, preventing its spreading throughout a plant.

With all heat-stripping processes, the loss of metallurgical properties must be considered. Some metals lose their strength (temper) if heated excessively and will soften and deform under load. Such metals are not suited for this type of stripping process. Burn-off ovens are frequently used for stripping paint from conveyor hooks and hangers.

**Molten salt.** Molten salt baths can strip paint films. The baths are composed of a mixture of various salts with melting points that may range from 600 to 900°F. The baths strip by burning the paint film, usually in less than 25 seconds. The higher the bath temperature, the faster the stripping action.

Hooks, hangers and floor grates are often stripped in salt baths because they can readily withstand the high temperatures. Products can be stripped as well if they can withstand the heat.

Large amounts of flame and smoke are immediately produced when paint-covered parts are immersed in salt baths. So much smoke forms that pollution controls are generally needed.

The burning of the organic resin and additives in the paint leaves behind inorganic pigment residues, which settle to the bottom of the bath container as sludge. Depending on how much paint is stripped, from 3 to 55 gallons of sludge may be produced a day. Each 55 gallons of paint sludge requires about 450 pounds of fresh salt mixture. The sludge must be separated out periodically and discarded.

Molten salt baths are extremely hazardous due to the high temperatures and because of the danger of splashing. Conveyorized part entry and exit is ideal so that operators need not be near the bath in case of splashing. An overhead hoist
can be used providing that operators are a safe distance away.

**Hot fluidized sand.** Beds of fluidized hot sand can effectively strip paint film. The sand is kept in a fluidized state by currents of air at 700 to 1000°F. The combination of heat and abrasive action of the sand provides rapid stripping action.

**Selecting a Stripping Process**

Various factors need to be considered before choosing a stripping process. These include:

- **Substrate characteristics**
- **Safety**
- **Environmental regulations**

**Substrate characteristics.** The nature of the substrate must be taken into consideration before selecting a stripper. Heat and strong chemicals can destroy or seriously damage sensitive materials.

**Safety.** Personnel should wear the required protective equipment and clothing for all types of paint stripping. In addition, plant areas surrounding the stripping should be checked thoroughly for damage susceptibility from the stripping. Proper ventilation is essential for stripping indoors. If stripping is conducted outside, the wind, temperature and precipitation conditions must be monitored.

**Environmental regulations.** Environmental and waste disposal limitations must be considered when selecting a stripping method.
Glossary

**Air Bearings** — A spinning shaft may be mechanically supported by roller, ball, or similar mechanical bearings, but also by a stream of air. Air bearings have limited load carrying capacity but require no lubricants.

**Air Dryers** — Used to remove moisture from compressed air. Dryers have three basic styles of operation: 1. deliquescent types have disposable drying agents and tend to be marginally effective for painting; 2. refrigerated dryers cool the air to condense out the water. Most paint systems use this type; 3. desiccant types have a double bed dryer and are able to achieve the lowest dew point air. The beds are alternately on-stream and back-flushed to regenerate their moisture absorbing qualities. Some plants with critical finish requirements use this style of dryer to reach dew points of $-40^\circ$ F.

**Air Knife** — A slotted jet of compressed air will act as an effective air knife to quickly blow superfluous water from parts, often before they enter a dryoff oven.

**Air Turbine** — 1. Electrical motor-driven fans that create volumes of relatively low-pressure atomizing air for spraying. Their output is referred to as turbine air; 2. an air-driven precision fan that is used to spin a paint atomizing disk or bell head.

**Alkali** — Substances that neutralize acids are termed alkali. The name is synonymous with caustic. The substances are helpful in aqueous cleaning by speeding soil removal and suspension.

**Amino Resins** — Nitrogen-containing compounds such as urea, melamine, or diethylene triamine are too rigid to be effective paint resins. The amino resins are used to crosslink polyester, epoxy, acrylic, alkyd, etc., resins to enhance their durability.

**Amperes (Amps)** — The ampere is an electrodynamic unit of measure for the quantity of current in a steady electric flow.

**Anode** — The anode is defined as the electrode at which chemical oxidation takes place. In electrodeposition (E-coating) the anode is indicated on diagrams by the positive (+) marking.

**Anolyte** — The water used to flush solubilizer molecules that form inside an electrocoating anode box. If used to flush a cathode box, it is termed catholyte.

**Arab Oil Embargo** — In 1973 a cartel of producers in Arabian countries withheld oil from the international market for a number of months in an attempt to raise prices for crude. Their efforts were devastatingly effective on all products that use petroleum, including paint products.

**ASTM** — Acronym for the American Society for Testing Materials. The Society publishes extensive standards used widely in manufacturing.
Autodeposition (Autophoretic) — A precipitation reaction of an organic resin occurs by the action of an acid that etches a metallic substrate. The ions of the oxidized metal codeposit with the vinyl emulsion resin in the autodeposition coating process.

Azeotrope — Miscible liquids that co-distill at a specific composition at a fixed temperature lower than that of a either single pure liquid form an azeotrope.

Barytes — A colorless crystalline solid, a form of barium sulfate (also called 'barite') used as a paint pigment.

Bells — A rotating head that is shaped to deliver paint forward in a circular pattern. The bell may be directed at any angle and be moved on robots or reciprocators, just as spray guns are.

Bentonite — A type of clay of varying composition, used as a paint pigment.

Blocked Isocyanates (Blocking Agent) — Isocyanates, normally extremely reactive with water, can only be used in waterborne coatings if they can be prevented from reacting before the water is baked out of the paint film. This is done by capping or blocking the isocyanate group with a thermally decomposable chemical. In the bake oven the water evaporates, the chemical cap decomposes and the isocyanate cross-links the paint. Blocked isocyanates are often employed for E-coat curing.

Blocking — When freshly painted parts are stacked they sometimes stick together if the paint is not fully cured. Sticking or blocking can be reduced by anti-block paint additives.

Bounce-Off, Bounceback — Paint droplets from air-atomized application have a tendency to rebound or bounce away from the surface due to the blasting effect of the air. These particles are called bounce-off or bounceback, as is the phenomenon itself.

Bulk Coating — The painting of large masses of small unhangable parts by a variety of possible techniques such as dip-spin and dipping.

Burn-Off Ovens — Paint stripping can be accomplished by combustion of the coating in gas-fired, burn-off ovens in which upper temperatures are controlled by injection of water spray into the oven.

Cathode — The cathode is defined as the electrode at which chemical reduction takes place. In electrodeposition (Ecoating) the cathode is indicated on diagrams by the negative (−) marking.

Caustic — Substances that neutralize acids are termed 'caustic'. The name is synonymous with alkali. They are helpful in aqueous cleaning by speeding soil removal and suspension.

CARC — An acronym for Chemical Agent Resistant Coatings, used on military equipment that might become contaminated by nuclear, biological, or similar chemical substances.

Cellosolve — Originally a trade name for the solvent family of mono-alkyl ethers of ethylene glycol, but the term is used generically now. A much-used solvent is
butyl cellosolve, for example, which chemically is ethylene glycol monobutyl ether.

**Centrifugal Coater** — See Dip-Spin Coater.

**CIE** — Acronym for the Commission International de Eclairage, a.k.a. International Commission on Illumination; established in 1931 the L,a,b color scale still widely used today.

**Continuous Coater** — An enclosed automatic spray booth that recovers and reuses oversprayed paint. A continuous coater is suitable for coating large volumes of similarly-sized parts.

**Cosolvents** — Waterborne paints frequently require water-miscible organic solvents (cosolvents) in addition to water for easier manufacture and improved application properties.

**Cross-Linking** — In enamel curing, the resin molecules react to form an extensive network polymer system. The processes whereby the separate molecules unite by chemical bonds into a single macromolecule is called cross-linking.

**Cup Gun** — A spray gun used with a siphon cup.

**Current Density** — A measure of the total electrical flow across a given surface area, frequently expressed in units of amps/square foot.

**Cyclone Separator** — Devices that move a particle-laden stream of air inside a funnel-bottomed enclosure around rapidly in a circular path. The relatively high mass of powder coating particles are thrown to the sides of the enclosure. They slide down through the funnel into a container for reuse.

**Deionized Water** — Water has all contaminant ions removed by a double-bed ion exchanger that switches H+ (hydrogen) ions for positive impurity ions and OH− (hydroxide) ions for negative impurity ions. The hydrogen ions and hydroxide ions then combine to form HOH (H₂O). Deionized water is equivalent in purity to distilled water but is much less costly to produce.

**Diluent** — While true solvents can be added in unlimited amounts to lower paint viscosity, it may be more economical to lower viscosity with less costly diluent solvents. Diluents alone cannot dissolve resins, but when added to a prepared paint they will lower the viscosity just as effectively as a true solvent. However, if too much diluent is added, the resin will separate out of solution and the paint becomes unusable.

**Dip-Spin Coater** — Bulk painting of small and unhangable parts can be accomplished by dipping a mesh basket of parts, followed by rapid rotation of the basket to remove excess paint. Parts from the dip-spin coater are dumped onto a belt for curing.

**Disks (Discs)** — Disks have rotating heads that deliver paint horizontally 360 degrees around the rotating head and use an omega loop conveyor line. The disk is mounted horizontally, usually on a vertical reciprocator.

**Dispersion Paint** — If the paint resin is not dissolved but uniformly spread throughout the formulation as a stable mixture by stirring, the coating is a
dispersion paint.

**E-Coating (Electrodeposition)** — In a method closely paralleling electroplating, paint is deposited using direct electrical current. The electrochemical reactions that occur cause water-soluble resins to become insolubilized onto parts that are electrodes in the E-coating paint tank. Subsequent resin curing is required.

**Eductor** — Eductors (venturi nozzles) located along E-coat return headers spaced laterally at intervals across the tank help to agitate the paint and prevent settling of pigments, resulting in cleaner deposited films.

**Electrons** — All matter contains vast numbers of sub-atomic particles of negative charge called electrons. Current flow in electric circuits can be thought of as a stream of electrons traveling through conducting wires.

**Emulsion Paint** — If the resin is present in a paint as dispersed globules coated by an agent that prevents their agglomeration, it is an emulsion paint.

**Enamel** — All paints, powder or liquid, that form cross-linking chemical bonds during curing. The majority of industrial finishes fall into this category.

**Faraday Cage** — Electrostatic application causes paint particles to be attracted to the nearest grounded object. This attraction force is often strong enough to pull paint particles out of their intended flight direction. Recessed areas on parts, since they require a slightly longer path for paint particles, often receive insufficient paint coverage. As a result, these Faraday Cage areas may need touch-up painting with non-electrostatic spray.

**Fatty Edge** — An excess bead of paint that forms on the bottom edges of parts when they are in the drippage zone following dipping or flow coating.

**Fluidized Bed** — Finely divided powders can be made into a fluidlike state by passing air through a porous plate bottom of a powder hopper. This permits the fluidized bed of powder particles to be used in dip tanks and to be transported in a manner similar to liquids.

**Flushable Electrode** — The anode in cathodic E-coating is often placed inside a semi-permeable membrane enclosure so that the excess solubilizer generated at the anode can be continuously removed by water pumped into the bottom of the enclosure. Flushable electrodes in anodic E-coating can also be used (but rarely are needed) for the cathode.

**Free Radical Polymerization** — Certain organic compounds will form highly reactive electron configurations by the action of UV light (or other activation sources). These reactive species are called free radicals because, to an extent, ‘free’ electrons are available for bonding. In free radical polymerization the reactive electrons chemical bonds to adjacent molecules and produce a cured paint film.

**Gas-Liquid Chromatography** — Both qualitative and quantitative analyses of gaseous and liquid mixtures are accomplished by separating the components carried in an inert gas stream through liquid-lined chromatographic columns; sometimes simply termed ‘gas chromatography’. 
Grain Refiners — Finer grain zinc phosphate crystals provide superior corrosion resistance and paint adhesion. Agents used in water rinses prior to zinc phosphating or in the zinc phosphatizing bath itself to produce smaller crystals are ‘grain refining chemicals’ or ‘grain refiners’.

Ground (Electrical Ground) — An object so massive that it can lose or gain overwhelmingly large numbers of electrons without becoming perceptibly charged is ‘ground’, in an electrical sense. The earth on which we stand is the best electrical ground possible.

Halogenated Hydrocarbons (Halogenated Solvents) — Halogens, including mainly chlorine, bromine and fluorine, can be substituted into hydrocarbon molecules to change both the physical and chemical natures of hydrocarbon compounds. These new products are collectively called the halogenated hydrocarbons. Their non-flammability is essential for operations such as vapor degreasing.

High-Solids — Solventborne coatings that are approximately 50 percent or greater in volume solids are generally considered to be high-solids paints.

Hot Water Curing — A particular version of autodeposition coating is cured by immersing parts in 180° water. Hot water curing is faster than oven curing for parts that act as a large heat sink, but is normally not used since it gives reduced corrosion resistance.

Hydroxides — The chemical opposites of acids. Hydroxides (e.g., sodium hydroxide, potassium hydroxide) neutralize each other; also known as caustics and alkalis.

Hygroscopic — An adjective for soluble liquids that absorb water strongly. Thinly spread deposits of such materials can absorb enough water to completely dissolve.

Ionized Air Cloud — Around the tip of an operating electrostatic spray gun is an invisible small cloud of air molecules that have picked up excess electrons. The electrons from the power pack flow off the end of the needle electrode at the gun tip. When paint droplets pass through the ionized air cloud they accumulate electrons that enable electrostatic attraction of the droplets to parts being coated.

Isocyanate — A somewhat toxic chemical compound or chemical group in a compound that is used to cross-link paint resins. It is a common component in urethane (polyurethane) coatings.

Latex — An emulsion of any organic resin in water is chemically termed a latex.

Lacquer — Any powder or liquid paint that does not cure by forming chemical cross-links but by polar attractions among molecules of the resin is defined as a lacquer paint.

Machine Vision — Used to describe the planning process of mechanically locating, identifying and determining the orientation of parts in a continuous operational flow.
MEQ (Milliequivalents) — The concentration of E-coat solubilizer in the bath is expressed in meq per liter.

Microhm — One millionth of a mho, a unit for measuring electrical conductivity.

Molecules — Compounds exist in identical groups of submicroscopic chemically-bonded elements. Each individual group is called a molecule of that compound. Water, for example, consists of molecules having 2 hydrogen atoms and 1 oxygen atom. The chemical formula, H₂O, indicates this molecular composition. Few molecules are that small. Polymers often have many thousands of atoms per molecule.

Molten Salt Bath — Mixtures of inorganic salts will melt at 650-900° F. Painted items immersed in these are rapidly stripped by combustion of the paint in the molten salt bath.

Non-Rinsed Conversion Coating — Several pretreatments for aluminum can be used when corrosion resistance requirements are not extreme that react fully enough to avoid the need for being flushed off the surface.

Ohm — A standard unit of resistance to electrical flow.

Ohmeter — Electrical resistance in a circuit is measured in units of ohms with this device.

Omega Loop — The conveyor for rotating disk paint applicators are shaped to produce a circular path around the vertically oriented disk that delivers paint from all 360 degrees of its circumference. The term was derived because the shape of the conveyor resembles the capitalized form of the Greek letter.

Permeate — The output of ultrafiltration is called ultrafiltrate or permeate.

pH — The relative acidity or basivity of aqueous liquids is indicated by the pH scale. Numbers below the neutral pH of 7 are increasingly acidic; and above pH 7, are increasingly basic (anti-acid).

Polarity — Every compound is made up of molecules, and all the molecules of each compound are identical and distinct in the arrangement, number and types of atoms that comprise them. As a result, molecules have a characteristic magnet-like property called polarity, which can vary from ‘no polarity’ to ‘extremely high polarity’. Compounds with uniform electron distributions are described as having ‘low polarity’; those with less uniformity have slight, moderate or high polarity, depending on the degree of electron nonuniformity.

Power-and-Free Conveyor — A power conveyor can use a separate pusher chain unattached to paint hooks riding freely on a separate support beam (as distinguished from a continuous power conveyor). This conveyor allows variable parts spacing and for parts to be held stationary even when the pusher chain is moving.

Power Conveyor (Continuous) — An electrically driven cable or chain power conveyor is mechanically attached to hooks, onto which parts to be painted are hung. The conveyor is used to carry parts through the painting process operations. When the line is operating, all individual hooks on the line will
continue to move and maintain their spacing.

**Pressure Pot** — Various-sized paint tanks with delivery tubes extending to the bottom inside the tank are pressurized with compressed air to force paint to the application device. The tanks, known as pressure pots, have bolt-on covers.

**Programming (Robots)** — Since robots are controlled by computers, programming is necessary to tell the robot electronically what to do mechanically.

**React-In-Place Conversion Coating** — See Non-Rinsed Conversion Coating.

**Reciprocator** — An automatic device to move a paint-applying tool in alternating directions along a straight or slightly curved horizontal or vertical path.

**Resin** — The polymer (plastic) component that cures to form a paint film is known by many names, such as binder, vehicle or resin.

**Reverse Osmosis** — By the natural process of osmosis, solvent is driven through a semi-permeable membrane separating solutions of different concentrations. This is how water reaches the top leaves of even the tallest trees, for example. Water always travels from the less concentrated to the more concentrated solution. In reverse osmosis, high pressures are applied to force water out of the concentrated solution, often to obtain pure (or purer) water. It has been used to produce drinking water from the ocean, and to reduce contaminants in process water.

**Siphon Cup (Suction Cup)** — When a special air spray tip is employed, a partial vacuum is created by the atomizing air just outside the fluid orifice. As a result, atmospheric pressure on the paint in a container connected to the fluid line (such as a siphon cup) will force paint up out of the container into the fluid line leading to the gun tip. The term siphon is actually a misnomer; suction is a more accurate description of the action.

**Slitting** — Wide coils of roll coated materials are cut into narrower widths.

**Solubilizer** — Since water is a polar solvent and resins are usually non-polar, the resins must be treated to increase their polarity if they are to be used in waterborne paints. Water-insoluble resins used for paints will form polar (and hence water-soluble) polymer ions when mixed (reacted) with compounds known as solubilizers.

**Solution Paint** — If the resin molecules are fully dissolved by solvents the paint is a solution paint.

**Static Electricity (Electrostatics)** — Electrons temporarily removed from various items can cause static charges. Whatever has excess electrons has a negative charge; the object from which electrons have been taken will be positively charged. Electrons will tend to jump from one object to another if at all possible in order to neutralize all charges. This behavior differs from an electrical current, or electrodynamics; instead it is electrostatics and charges are termed static electricity. Styrenated Alkyd — Styrene is allowed to react with alkyd resin to improve the water and alkali resistance. The drying speed
of a styrenated alkyd polymer is also better.

**Surface Tension** — Liquids tend to reduce their surface area due to unequal intermolecular attractive forces in this region. A low degree of surface tension is preferred for liquid coatings to maximize adhesion and minimize edge-pull and ‘fisheye’ effects.

**TGIC** — Triglycidyl isocyanurate is a complex chemical that is used to cross-link paint, especially polyester powders, to increase exterior durability.

**Thermally-Inverse Solubility** — Nearly all solids follow the pattern of becoming more water-soluble as temperature increases. A relatively few exceptions decrease in solubility with a rise in temperature.

**Thermosetting Resin** — Resins which will not melt or soften to any appreciable extent when heated. They will soften but not dissolve in any solvents.

**Thixotrope** — By forming loosely-held three-dimensional particle networks within paint fluids, thixotropes cause temporarily high paint viscosities. Agitation of the paint by stirring, pumping, spraying, etc., quickly destroys the networks and viscosity drops sharply. When agitation is halted, the networks reform rapidly and paint viscosity again rises.

**Toll Coater** — A trade term for custom or contract coaters who coil coat for other companies.

**Toners** — Unpigmented paints may need to be transparent but shaded to a specific color. Soluble colorants, i.e. toners, produce this effect and give a tinted clearcoat.

**Transfer Efficiency** — The percentage of applied paint used that is deposited on the parts is called the paint transfer efficiency. The balance of the paint goes onto the booth surfaces, hooks, filters, etc.

**Ultrafiltrate** — The output of ultrafiltration; also called permeate.

**Ultrafiltration** — Ultrafiltration uses low-pressure membrane filtration to separate small molecules from large molecules and fine particulates. For example, E-coat rinse water is extracted from the paint bath by ultrafiltration.

**Ultrasonic Cleaning** — Vibrational frequencies slightly higher than those audible are used to agitate immersion cleaning tanks, a process labeled ‘ultrasonic cleaning’. Microbubble formation in the liquid accelerates dislodgement of soils.

**VOC** — An acronym for Volatile Organic Compounds, emissions of which are subject to governmental regulations.

**Voltage** — A measure only of the potential difference (force or pressure) in electrical systems; it does not indicate amounts of current.

**Wier** — The (often adjustable) barrier that controls the paint depth in an E-coat tank and over which the paint flows to the circulation pump and is filtered.
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