

Quali*team* International



The Powder Coaters Manual

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Index

I. Powder Coating Materials

1. [Thermoplastic Powders](#)
2. [Thermoset Powders](#)
3. [Coating Comparison](#)
4. [Coating Selection](#)
5. [Powder Storage](#)
6. [Powder Particle Size](#)

II. Part Preparation Processes & Equipment

1. [Substrates](#)
2. [Cleaning Processes](#)
3. [Rinsing](#)

III. Powder Application Processes & Equipment

1. [Fluidized Bed Application](#)
2. [Electrostatic Spray Application](#)
3. [The Powder Delivery System](#)
4. [Determining the Application Package](#)
5. [Selection of the Application Package](#)
6. [Control of Powder Spray Application Equipment](#)

IV. Powder Booths & Recovery Systems

1. [Powder Booths](#)
2. [Recovery Systems](#)

V. Curing Process & Equipment

1. [Convection Cure Ovens](#)
2. [Combination Dry-off/Cure Ovens](#)
3. [Infrared Curing](#)
4. [Oven Heat Containment](#)
5. [General Oven Design & Operation](#)
6. [Summary](#)

VI. Material Handling

1. [Batch Carts](#)
2. [Racking](#)
3. [Types of Conveyor](#)

VII. Finished Film Testing

1. [Color & Gloss Measurement](#)
2. [Film Thickness](#)
3. [Film Hardness](#)
4. [Flexibility](#)
5. [Impact Resistance](#)
6. [Abrasion Resistance](#)

VIII. Process Control

1. [Definition of Quality](#)
2. [System Design](#)
3. [Air Management](#)
4. [Surface Defects](#)
5. [Racking](#)
6. [System Process Controls](#)

IX. System Maintenance

1. [Chapter 1](#)

X. Troubleshooting

1. [Application Problems](#)
2. [Adhesion](#)
3. [Outgassing](#)
4. [Masking](#)
5. [Halos](#)
6. [Seeds](#)

XI. Cost Analysis

1. [Gase Use in BTU's](#)
2. [Electrical Consumption](#)
3. [Compressed Air](#)
4. [Cost Comparison of two coating processes](#)
5. [Quoting a part](#)
6. [Return on Investment](#)

Powder coatings are finely ground plastic particles consisting of resin, crosslinker in thermoset powders, pigments & extenders, and various flow additives and fillers to achieve specific properties. When they are heated, these plastic particles melt to form a continuous film, typically a very durable and chemical resistant film.

Powder coatings are applied as a dry material and they contain very little, if any, Volatile Organic Compounds (VOC). The raw material is literally a powder, mixed dry, extruded, and ground into the final material. An environmentally safe coating that can provide a variety of high quality finishes makes powder a popular alternative in the ecologically sensitive climate that we live in today.

Powder materials may be thermoplastic or thermoset. Thermoplastic powders do not chemically react in a cure phase. They are typically used for functional applications and applied in thick films, typically 6–12 mils. They are used for a wide range of applications that require a tough finish with impact resistance and/or chemical resistance.

Thermoset powder coatings are applied and then cured in an oven at a certain temperature for a certain time. The cure process will cause a chemical crosslinking to take place, changing the powder into a continuous film that will not remelt. Thermoset powders are used for a variety of functional and decorative applications and usually applied in thinner films, typically in a film thickness of 1.5 to 4 mils.

Powders can be formulated to meet a variety of appearance or performance characteristics. This would include the film thickness, gloss, texture, color, and performance (hardness, chemical resistance, U.V. Resistance, high temperature resistance, etc.) of the coating. Powders are available with very smooth finishes, hammertones, wrinkles, and metallics.

A typical thermoset powder will have a resin as the primary film forming component, several pigments for color, flow aids, and a cure agent. The dry ingredients are blended at high speed to create a homogeneous mixture and then fed into an extruder for melt mixing. The taffy-like extrudate is cooled and chipped. The chips are ground to a very specific particle size distribution and packaged for shipment.

The particle size is important to the performance and appearance of the coating. Particle size can affect the application and appearance characteristics of the coating. This will be discussed later in this chapter.

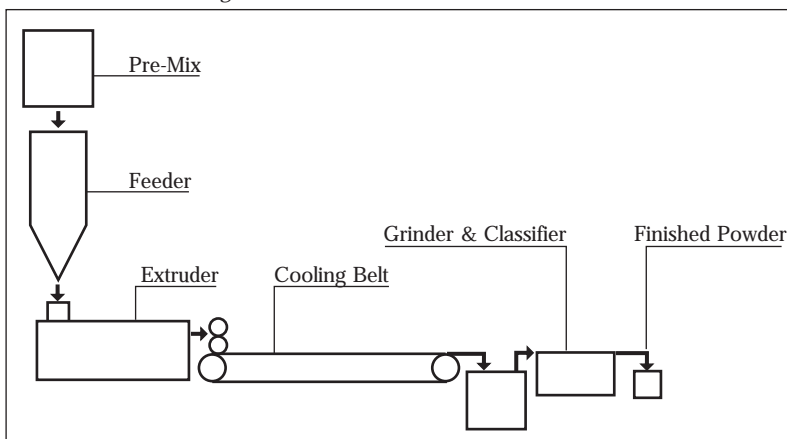
1 Thermoplastic Powders

There are three primary resins used in thermoplastic powders, vinyls, nylons and polyesters. These materials are used for some food contact applications, playground equipment, shopping carts, hospital shelving and other applications. Few of the thermoplastics have the broad range of appearance properties, performance properties and stability that are required in applications that use thermoset powders. Some typical properties of the different resins are listed in the chart on page I/4.

Thermoplastic powders are typically high molecular weight materials that require high temperature to melt and flow. They are commonly applied by fluidized bed application and the parts are both pre-heated and post-heated.

Most of the thermoplastic powder coatings have marginal adhesion properties so that the substrate must be blasted and primed prior to application.

Powder Manufacturing Process



Physical & Coating Properties of Thermoplastic Powders

| Property | Vinyls | Nylons | Polyester |
|-------------------------------------|-----------|-----------|-------------|
| Primer Required | Yes | Yes | No |
| Melting Point °F | 266-302 | 367 | 320-338 |
| Typical Pre/Post Heat °F | 544/446 | 590/482 | 572/482 |
| Specific Gravity, G/CM ³ | 1.20-1.35 | 1.01-1.15 | 1.30-1.40 |
| Adhesion ^a | G-E | E | E |
| Surface Appearance | Smooth | Smooth | Slight Peel |
| Gloss, 60° | 40-90 | 20-95 | 60-95 |
| Pencil Hardness | HB-2H | B | B-H |
| Flexibility ^b | Pass | Pass | Pass |
| Impact Resistance | E | E | G - E |
| Salt Spray Resistance | G | E | G |
| Weathering | G | G | E |
| Humidity | E | E | G |
| Acid ^c | E | F | G |
| Alkali ^c | E | E | G |
| Solvent ^c | F | E | F |

E = Excellent G = Good F = Fair P = Poor

^a With Primer Where Indicated

^b No Cracking, 1/8 Inch Diameter Mandrel Bend

^c Inorganic, Dilute

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Polyvinyl Chloride (PVC)

Polyvinyl chloride powder coatings provide good durability, chemical and water resistance and they can be formulated for FDA approved applications such as frozen food shelving and dishwasher baskets. The finish is somewhat soft, glossy and flexible. It has good resistance to water and detergent at high temperatures for long periods of time.

Polyolefins

Polyethylene produces soft and waxy films. Polypropylene powder has much in common with the plastic surface of solid polypropylene. Like most thermoplastic powders, they are durable and resistant to many chemicals and detergents. Some solvents and detergents can break them down quickly.

In addition to the toughness and chemical resistance common to other thermoplastics, polyethylene is an excellent electrical insulator. It also is used to coat laboratory equipment because the surface is very cleanable.

Nylon

Nylon resins (polyamides) produce powders that are tough, smooth, chemical and solvent resistant, and very abrasion resistant. Most of the time a nylon powder will require a primer to achieve the adhesion level needed for higher performance applications. Nylons can be formulated for food contact applications, they make an excellent coating for shelving and they are also widely used on bearing surfaces to prevent breakdown from mechanical abrasion. Some nylons are also used for outdoor applications such as light fixtures or seating.

Polyester

Polyester-based thermoplastic powder materials have better than average adhesion properties and good UV resistance characteristics. However, they are somewhat more difficult to apply than nylon materials and not as resistant to abrasion or solvent. Polyesters are used on some outdoor applications such as patio furniture due to good outdoor durability characteristics.

PVDF (Poly-Vinylidene Fluoride)

PVDF based coating materials have excellent weathering characteristics. They also have excellent resistance to chemicals with the exception of hydrocarbon solvents. They are used to coat piping and valves used in chemical process industries. Usually, a chromate primer is recommended.

2 Thermoset Powders

Thermosetting powders are much more widely used than thermoplastics. They are primarily composed of relatively high molecular weight solid resins and a crosslinker. Thermoset powders are used for a wide variety of decorative and protective applications. They are applied by the electrostatic spray process, heated to the necessary temperature and cured.

The primary resins used in the formulation of thermosetting powders are:

- Epoxy
- Polyester
- Acrylic

These primary resins are used with different crosslinkers to produce a variety of powder materials. Many crosslinkers, or cure agents, are used in powder coatings, including amines, anhydrides, melamines, and blocked or non-blocked isocyanates. Some materials also use more than one resin in hybrid formulas.

When a thermoset powder is applied and subjected to heat it will melt, flow and chemically crosslink to form a finished film. The chemical reaction in the cure cycle creates a polymer network that provides excellent resistance to coating breakdown. A thermoset powder that has cured and crosslinked will not melt and flow again if subjected to heat a second time.

Epoxy

Epoxy powders were the first commercially available thermoset materials and they are the most commonly used of the thermosetting powders today. They are available in a wide range of formulations for thick film functional applications and thin film decorative applications. They provide excellent toughness, chemical resistance, corrosion resistance and flexibility. The primary drawback with epoxies is that they will chalk when subjected to UV radiation. For this reason they are rarely used for outdoor applications.

Functional Epoxy Powder Applications

Functional epoxies are commonly used for electrical insulation and corrosion protection. Some typical applications for functional epoxies are electric motors, alternators and electrical control junction boxes, taking advantage of its insulating properties. Because functional epoxies also have very good chemical resistance, they are used in a variety of applications where corrosion resistance is required, such as piping, under the hood automobile components and concrete "rebar."

Decorative Epoxy Powder Applications

Epoxies are often used for decorative applications. They can be formulated to provide a variety of glosses, colors and textures and applied in relatively thin films of 0.5 to 3 mil, still providing the toughness and durability of the functional coatings. Typical applications include metal office furniture, shelving, interior car parts, and toys.

Epoxy Polyester Hybrids

Epoxy-Polyester "Hybrids", like the name implies, combine epoxy resins with polyester resins to form a powder with most of the same properties as epoxies. Although some hybrids are less resistant to chemicals and solvents, they are tough, flexible and competitively priced.

Hybrids are likely to be used in many of the same applications as epoxies. In addition to the slight improvement in weatherability, the polyester resin sometimes provides some improvement in charging characteristics for electrostatic application.

Polyester Powder

Polyester resins are used to formulate urethane polyesters and polyester triglycidyl isocyanurate (TGIC) materials.

Urethane Polyesters

Urethane cured polyester powders have excellent resistance to outdoor environments, toughness and very good appearance characteristics at 1 to 2 mil film thickness. A smooth, thin film that resists weathering and physical abuse makes the urethane polyesters a popular finish for high quality products.

It is common to block the crosslinker in urethane polyesters with *e*-caprolactam. To begin the crosslinking process, the material must reach a temperature above the blocking agent threshold. With *e*-caprolactam, unblocking occurs at approximately 360 °F (182 °C). Therefore, temperatures must be higher than 360 °F to start the melt phase of the cure cycle.

Powders containing *e*-cap are usually sensitive to films thicker than 3 mils. Thicker films with these urethanes may lose some of their mechanical properties and they may exhibit outgassing effects due to *e*-caprolactam evolution.

They are used for exterior applications such as patio furniture, automotive wheels and trim, lawnmowers and a wide range of other products requiring high quality, decorative finishes comparable to wet coatings.

Polyester TGIC

Polyester TGIC coatings use the epoxy functional crosslinker triglycidyl isocyanurate (TGIC). TGIC's have very good adhesion characteristics, corrosion resistance and exterior durability. They can typically be cured at lower temperatures than urethanes and/or have shorter cure cycles. In the cure cycle, they have good overbake characteristics and they are less sensitive to outgassing. They also provide good edge coverage and tough, thick films (3–5 mil/75–100 μ) due to the inherent higher melt viscosity of the non-blocked TGIC crosslinker. They have equal corrosion resistance to urethane polyesters but they are somewhat less resistant to chemicals.

Some typical applications are automotive wheels, air conditioners, lawn furniture, and air conditioner cabinets.

Acrylic Powders

Like the polyesters, acrylics give excellent exterior durability. Common acrylic-based materials include urethane acrylics (hydroxyl functional resins), acrylic hybrids (acid functional resins) and glycidyl methacrylate acrylics (GMA) (epoxy functional resins).

Urethane acrylics require cure temperatures of 360 °F (182 °C). Like urethane polyesters, they may exhibit problems with outgassing at thicker films (3 mils/75 μ). They offer excellent thin film appearance, good chemical resistance and hard films. Flexibility and impact resistance is usually poor.

GMA acrylics can be cured in less time or lower temperatures than the urethane acrylics and they also can provide superior weathering characteristics. They make excellent clear coats over brass or chrome due to their exceptional clarity. Like the urethane acrylics, flexibility is somewhat limited. They can be applied in films greater than 3 mils (75 μ) without the risk of outgassing that is characteristic with the urethanes. GMA acrylics are typically not compatible with other resins and are run in systems that are isolated from other powders.

Acrylic hybrids combine the acrylic resin with an epoxy binder. They are somewhat better than a polyester/epoxy hybrid but still not considered acceptable for outdoor use. The mechanical properties that are characteristic in epoxies are a benefit of these materials and they have much better flexibility than other acrylics.

Because of their good appearance, tough surface, exceptional weatherability, and excellent electrostatic application characteristics, acrylics are frequently used for applications on products that have very high quality standards. Appliances, automobiles and other products that require durability and long life in a harsh environment are good candidates for acrylic powder coatings. Typical applications include automotive wheels, plumbing fixtures and vending machines.

Research has been conducted to determine the suitability of acrylic powder coating as a clear coat on automotive bodies. While the United States automobile manufacturers continue to evaluate this application, one European manufacturer is using it in production.

3 Coating Comparison

The decision on what powder to use depends on the specific appearance and performance requirements of the end product. The end user must determine what specific properties they want in the coating and communicate that to the formulator.

When selecting a powder, several variables must be considered.

- Cost of the powder (applied)
- Performance characteristics
- Application characteristics
- Appearance

The proper coating is a balance of these variables. Coating manufacturers can help the applicator in the selection process. Given a particular specification, they can often formulate a powder to meet a specific application at a reasonable cost, particularly if the volume is high.

The comparison charts below show some of the performance properties and typical uses of the various resins.

Epoxy

| Property | Range |
|--|--|
| Hardness (pencil) | HB-7H |
| Impact Resistance (in.-lbs) | 60-160 |
| Gloss (60 deg. meter) | 3-100+ |
| Color | All colors, clear and textures |
| Salt Spray | 1,000 hrs. |
| Condensing Humidity | 1,000 hrs. |
| Cure range (Typ. 2 mil (0.05mm) film - time at Metal temp.) | 3 min at 450 °F (232 °C) to 25 min at 250 °F (121 °C) |

Epoxy hybrids

| Property | Range |
|--|---|
| Hardness (pencil) | HB-2H |
| Impact Resistance (in.-lbs) | 60-160 |
| Gloss (60 deg. meter) | 10-100+ |
| Color | All colors, clear and textures |
| Salt Spray | 1,000 hrs. minimum |
| Condensing Humidity | 1,000 hrs. minimum |
| Cure range (Typ. 2 mil (0.05mm) film - time at Metal temp.) | 10 min at 400 °F (204 °C) to 25 min at 300 °F (149 °C) |

Urethane polyester

| Property | Range |
|--|---|
| Hardness (pencil) | HB-4H |
| Impact Resistance (in.-lbs) | 60-160 |
| Gloss (60 deg. meter) | 15-95 |
| Color | All colors, clear and textures |
| Salt Spray | 1,000 hrs. |
| Condensing Humidity | 1,000 hrs. |
| Cure range (Typ. 2 mil (0.05mm) film - time at Metal temperature) | 10 min at 400 °F (204 °C) to 25 min at 320 °F (160 °C) |

TGIC

| Property | Range |
|--|---|
| Hardness (pencil) | HB-4H |
| Impact Resistance (in.-lbs) | 60-160 |
| Gloss (60 deg. meter) | 20-90 |
| Color | All colors, clear and textures |
| Salt Spray | 1,000 hrs. minimum |
| Condensing Humidity | 1,000 hrs. minimum |
| Cure range (Typ. 2 mil (0.05mm) film - time at Metal temp.) | 10 min at 400 °F (204 °C) to 30 min at 300 °F (149 °C) |

I

Coating Selection

Acrylics

| Property | Range |
|--------------------------------------|--------------------------------|
| Hardness (pencil) | H-4H |
| Impact Resistance (in.-lbs) | Excellent, 40-100 |
| Gloss (60 deg. meter) | 10-90 |
| Color | All colors, clear and textures |
| Salt Spray | 1,000 hrs. minimum |
| Condensing Humidity | 1,000 hrs. minimum |
| Cure range (Typ. 2 mil (0.05mm) film | 10 min at 400 °F (204 °C) to |
| - time at Metal temp.) | 25 min at 350 °F (177 °C) |

Note: All of the performance properties are dependent on proper pretreatment of the substrate, proper application, and proper curing.

4 Coating Selection

The first step in the coating selection process is to define your finished product requirements. With a specification, a manufacturer can work with a coating supplier to get just the right coating formulated for their specific need.

In selecting a thermosetting powder type from a powder coating supplier, it is advised that the following thoughts be kept in focus throughout the selection process and during negotiation with suppliers.

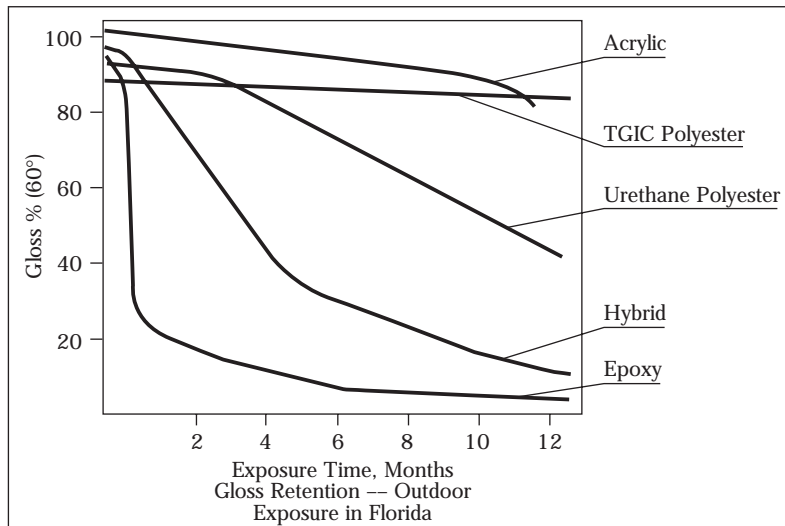
The key selection factors are:

- Demonstrated film performance
- Demonstrated application characteristics
- Cost performance balance

Testing of performance issues is important. For example, if the product will be used outdoors, resistance to UV light and outdoor weatherability should be tested.

The exposure chart on page I/12 shows the results of testing for comparative gloss retention of different powder formulations.

The properties of any particular powder will vary even if they are the same chemistry. Formulators can produce materials to meet specific needs.



This is a summary of the key properties of each generic type of thermosetting powder as discussed.

| | |
|---------------------|---|
| Epoxy: | Tough Chemically resistant Poor exterior durability (chalking) |
| Hybrid: | Decorative film performance similar to epoxies Some UV and overbake advantages Not exterior durable |
| Polyester Urethane: | Exterior durable Thin film powder coating |
| Polyester TGIC: | Exterior durable Good edge coverage Thicker films are no problem |
| Acrylic: | Excellent weatherability Excellent appearance Good-fair impact resistance |

5 Powder Storage

Powder storage areas should be reasonably cool, dry and free of air borne contaminants. Some powders are more stable in storage than others, so it is important to know which materials are most sensitive and what conditions are required to keep them in good condition.

Heat

Most powders will withstand a certain amount of exposure to heat in storage. Temperatures of 100–120 °F (38–46 °C) usually will not hurt the material. If the temperature is greater than this, several physical changes may take place. The powder can sinter, pack, or clump in the container. Tall containers or boxes stacked high can add to this problem because of the weight of the powder on itself. Boxes should not be stacked more than 3 high. Usually this clumping can be eliminated by passing the powder through a screen or sieve but this is very labor intensive.

Powders with low temperature curing mechanisms may undergo a chemical change when exposed to excessive heat. Once this happens, the powder will lose its original flow characteristics and must be scrapped. Most powders are formulated with blocking agents that prevent curing below 200 °F (93 °C), so this is not usually a problem.

Humidity

Powder will absorb moisture if the air in the storage area is above 60% relative humidity. This will cause it to clump together, resist fluidization and flow poorly. In most cases, the clumping can be eliminated by a combination of stirring and fluidizing for a few minutes. Still, it is better to store powder at a range of 40 to 60% RH.

If powder is stored in a controlled environment within these parameters, it will normally remain stable for at least one year. Storage in a controlled environment will provide more consistent behavior of the powder during application.

To avoid problems with powder materials, storage areas should be controlled as follows:

- Control temperature to 80 °F (27 °C) or less.
- Control the relative humidity between 40 and 60% RH.

- Rotate stored powder so that it is not kept in storage for extended periods of time. First in, first out.
- Avoid leaving containers of powder open on the shop floor where the powder can easily pick up moisture and dirt.
- Precondition the powder before spraying by fluidizing it for a few minutes prior to application.

Like many of the recommendations in this book, these precautions are not absolutely necessary to the application of powder. However, following them will produce the best possible results with the least possible labor. Proper storage and a little patience to achieve correct fluidization will help contribute to consistent results.

6 Powder Particle Size

The size of the powder particle can have an influence on the behavior of the material in the delivery system, the charging system and the final film characteristics. The original grind size is determined by the manufacturer to provide certain deposition and appearance characteristics. The powder coater must understand the role of particle size in the electrostatic process and maintain a consistent blend when reclaimed powder is used.

The consistency of powder flow from the gun begins in the feed hopper. Steady, uniform fluidization is required to achieve a consistent flow through the pumps and out of the gun. As the concentration of fine particles increases the powder coating material will begin to clump together and resist fluidization. Finer particles fill the voids between the larger particles and force the operator to use higher air pressure.

The air entering the fluidized bed will follow the path of least resistance and higher pressure will often cause geysering. The surface of the fluidized powder is inconsistent with large bubbles and dead spots. This condition will cause the air to surge and deliver inconsistent amounts of powder to the pick-up tube. If the condition is not too severe the operator may continue to spray but the parts will have uneven film thickness and possibly surface blemishes. If the condition is severe the gun will spit a large volume of powder onto the surface and leave a blotchy mound of powder.

Higher delivery pressures may also be needed to move the compacted powder through the hose. This higher pressure will cause excessive impact fusion at contact points throughout the delivery system, particularly in bends of the hose or around the deflector tip. Higher delivery pressures will also result in higher velocity, which can reduce powder transfer efficiency. Higher pressure will also cause more grinding action as the powder travels through the system, breaking down the powder and adding still more fines.

Finer particles have more surface area per given weight than larger particles so they tend to pick up more moisture. The higher moisture content contributes to clumping. There are physical and chemical properties of powder materials that can affect the transfer efficiency. If a powder seems to perform below the level of the other powders run on the same line the powder supplier should be consulted to see if it can be altered so that it will charge more efficiently.

The range and concentration of particle size can also affect transfer efficiency. Smaller particles carry more charge per unit weight and become self limiting at thinner films. Since back-ionization occurs at the self limiting point, a higher concentration of fine particles will contribute to surface disruptions at thinner films.

Smaller particles also have less mass and are more likely to be influenced by the air flows and weaker electrostatic lines. Larger particles are more likely to have straight line motion and be affected by strong electrostatic force lines or gravity. This particle size related behavior has an impact on electrostatic wrap and penetration of faraday cage areas.

The electrostatic field lines generated from the corona gun will tend to concentrate on the external edges and bend around to the back of the part. Since the finer particles tend to be more influenced by the weaker field lines that connect to the back of the part they will contribute more to wrap.

The fines also deposit on the edges more readily and become self-limiting at thinner films, making it more difficult to penetrate Faraday areas when there is a high concentration of finer particles. Larger particles, since they are slower to self limit and have truer straight line motion, are more successful in penetrating inside corners.

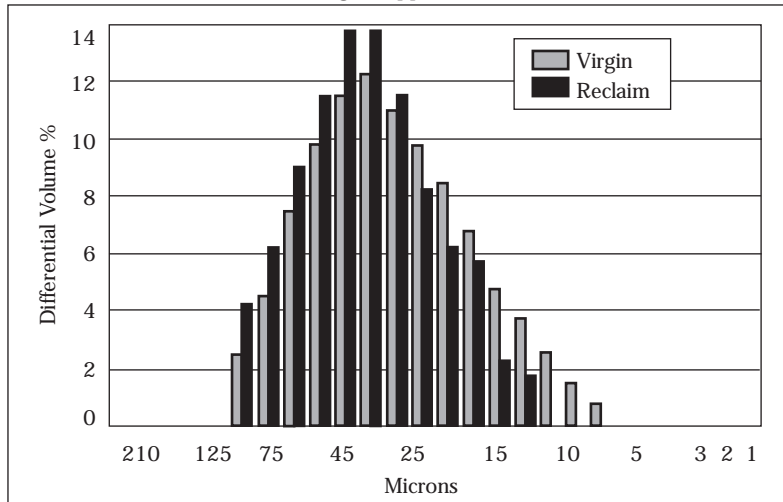
When film builds are drifting lower and penetration is becoming more difficult the powder particle size blend may have too many fines.

Smaller powder particles are easily influenced by air flows in the application area and more likely to drift away from containment. Since uncontained powder is a dirt source the finer particles can be a contributor to dirt rejects.

Because of the ability to collect over-spray for reuse, some operators are not overly concerned about first pass transfer efficiency. However, recycling of powder has a negative impact on the material. It alters the classification of the particle size, it degrades application performance, contamination may be added to the reclaimed material and some over-spray will need to be scrapped. Good practices in application must be designed to provide high first pass transfer efficiency to reduce over-spray.

Reclaimed powder is mixed with virgin powder in a consistent volume for consistent performance. It is important to maintain a consistent ratio of virgin to reclaim powder for the best possible transfer effi-

Particle Size Distribution, Cartridge Hopper



ciency. Experience with a given powder will help to determine what the ratio should be. A sensible starting point is 50/50. If the deposition is good then 50/50 is a good ratio of virgin to reclaim. If the deposition is worse than the virgin material it may be necessary to reduce the volume of reclaim in the blend.

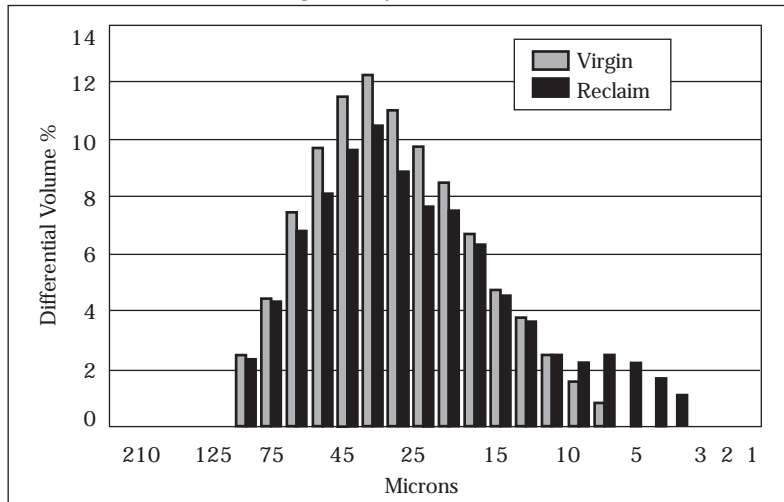
Film characteristics, such as thickness and smoothness, are also affected by the grind size. In general, an overall coarser blend will build a thicker film and a finer grind will provide a thinner film.

Film smoothness is partly dependent on an even distribution of various sized powder particles. Larger particles take longer to melt and they may not completely level out during the cure cycle. If a grind is too coarse it may cause excessive texture called orange peel. An excess of fines will cause the film to reach the self limiting point faster and start back ionization, resulting in "electrostatic orange peel."

Particle Size Measurement

Because of the impact that particle size has on the coating process it is important to be able to accurately measure the grind size for speci-

Particle Size Distribution, Virgin vs. Cyclone Recovered Powder



fication of a material and for adjustments to the coating operation. Many coaters do not have this capability and must rely on the coating supplier to perform the test for them. Understanding the measuring process and the how the data is organized and analyzed can help a coater develop process control measures.

The grinding operation in powder manufacturing produces particles of varying size and shape. This collection of particles is called the particle size distribution. A sample of the virgin material is used to determine the particle size distribution as received.

Collection of the sample should consider the natural separation that can take place in the container. Coarser particles tend to migrate to the top while the finer particles settle at the bottom. In order for the sample to be a true representation of the bulk material it should be taken from a level somewhere in the center of the container. The scoop that is used for the sample should be metal rather than plastic to help avoid frictional charging and the relative humidity should be between 40 to 60%. These measures will help provide a truly representative sample.

In order to compare the reclaimed powder to the virgin material or a mix of the two to the virgin material, a sample is compared to the original bulk powder as received. The results are used to construct a graph, a table or a statistical summary for comparison.

There are several methods by which particle size distribution can be measured. Different methods measure different attributes so it is difficult to compare results from two different methods. Optical methods that are used may not always be completely accurate but they are useful for comparing relative particle size differences.

Summary

It is important to understand the influence of powder particle size on the application of the coating. The particle size from the manufacturer will be altered by the application process and these changes must be managed to provide consistent results. Effective communication of particle size data can help define the best powder and provide information for process control.

Raw metals have surface characteristics that can cause poor adhesion, surface defects, and premature corrosion if they are coated without part preparation. Prior to the application of a powder coating, the metal must be cleaned and treated to provide good adhesion, appearance and corrosion resistance.

Powder coating a metal part provides the necessary appearance and performance qualities. The finished film acts as a physical barrier to moisture. If the coating is damaged and bare metal is exposed, corrosion can form and spread. Pretreatment not only provides a better bond of the coating to the part, it also helps to prevent the undercoat creepage of corrosion, adding value to the product and extending its useful life.

The term pretreatment refers to the mechanical or chemical surface treatment for a manufactured product. The part surface, or substrate, needs to be clean and prepared for the application of a coating. Pretreatment may be as simple as a solvent wipe or it may be a multi-stage spray washer that cleans the part and applies a conversion coating for good paint adhesion and performance. The level of pretreatment employed is directly related to the appearance and performance requirements of the product in the field.

The powder coating will not hide defects and the performance of coating is directly related to the condition of the substrate. Application of the coating over a contaminant will prevent the coating from forming a tight bond to the substrate and if the contaminant lifts off, so will the coating. Dirt particles will not dissolve or be hidden by the coating. To ensure good appearance and adhesion, the part must be clean.

In addition to cleaning, it may be necessary to develop a conversion coating on the surface prior to coating application. With the exception of some precious metals like silver, gold and platinum, metals react with air to form an oxide layer on their surface. Water molecules are tightly held to this oxide layer. This is not a good surface condition for bonding.

There are a number of options to the type and extent of the pretreatment process used. In determining which process is required for a particular situation, one must consider the performance requirements

of the final part, the coating being applied, the type of substrates being coated and the different types of pretreatment available. A knowledge of metal surfaces and the condition of their surfaces prior to coating is essential.

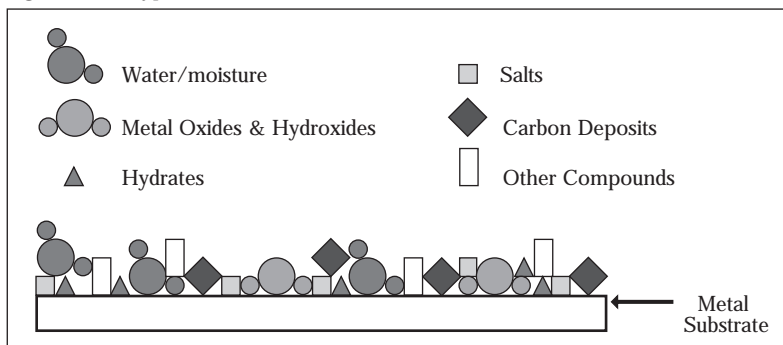
1 Substrates

Each class of metals has its own unique surface characteristics that will affect the performance of an applied powder finish. These characteristics include the not only the solid properties of the base metal itself but also the many surface attributes that are determined by the chemical composition and processes used in the manufacture of the metal.

These surface attributes consist primarily of a mixture of the oxides, hydrates, and salts of the metallic elements which make up the metal composition and very little of the metal itself. In addition to these natural constituents, a number of contaminants are present.

For example, on steel these would include surface carbons, oils, lubricants, metal fines, non-metallic surface inclusions, rolled-in scale, large surface carbides, dirt, corrosion products, and by-products of bacterial action, mildews and other fungal deposits. Zinc surfaces will have oils, lubricants, corrosion products, metal fines, dust, dirt, and other extraneous soils. Aluminum will be similar to zinc but also include heavy deposits of aluminum oxide. The aluminum oxide is not considered a

Figure 2-1 - Typical Metal Surface Constituents



classic contaminant in itself but it may interfere with the removal of other contaminants.

There is no universal part preparation method that can be used to deal with all of the different metals and their respective surface contaminants and be effective in all cases. An understanding of the different metals, their typical surface characteristics and the different treatment methods is very important to the powder coater.

Steel

Steel is an alloy of iron and carbon with small amounts of other elements. The steel manufacturing process can be varied to produce steels with different properties and gauges. Heavy gauges of steel are typically hot-rolled steel. Hot-rolling is the first step in the development of steel slab. It produces a surface that carries a layer of mill scale that is developed after the steel is rolled, during the cooling process. The scale is relatively adherent to the metal surface beneath it but it is often cracked and loosened during the manufacturing process. Application of powder over HRS surfaces that have not had the scale removed is very likely to result in adhesion failure. Complete and reliable removal of mill scale requires acid pickling or mechanical cleaning.

Welded areas on HRS may cause further problems with adhesion failure and application. The welding process leaves a rough surface with dried-on compounds, oils and stains that can interfere with application and adhesion. Welded areas should be mechanically cleaned by wire brush or blasting to remove contamination that will resist chemical cleaning.

Cold rolled steel (CRS) is a further reduction in the process that produces steel in thinner gauges (0.005 to 0.080 inches or 0.0127 to 0.20 centimeters thick) and has a finer microstructure than hot-rolled steel. It has the same basic elements as the HRS but not the mill scale and heavy carbon smut. CRS sheets will normally have light oil on the surface to act as a rust inhibitor but it is relatively clean and free of oxides. Chemical cleaning can be a very satisfactory way to prepare CRS for powder coating.

Some products, such as automotive panels and wheels, are manufactured from high strength-low alloy steels (HSLA). HSLA steels have

small amounts of alloying elements included in their composition to provide better strength-to weight ratios. HSLA will normally respond well to the same treatment methods as other carbon steels and oxidation can be removed by grit blasting. Blasting to a near-white or white metal clean surface may produce some "shadowing," due to the nature of the oxides on the surface. Typically, this is not a problem and coating adhesion is good over these surfaces. Some HSLA materials contain silicone, which can accumulate as oxides on the surface and interfere with subsequent cleaning and conversion coating processes.

Stainless Steel

Stainless steel (SS) is relatively free of the iron hydrates that are a common component on the surface of regular grades of carbon steel. SS should be cleaned to remove the surface oils and dirt from manufacturing and handling. Many stainless steel products do not have a protective coating because they are not sensitive to ordinary atmospheric conditions.

The passive oxide layer on stainless steel is relatively inert to alkaline cleaners and other chemical products that are commonly used on carbon steel. Normal cleaning will remove loose soils but it will not create a surface that is receptive to iron phosphating. Acid etchants or mechanical abrasion processes are sometimes used to remove the oxide layer and create a slightly roughed surface that is better for adhesion of the coating. These processes help promote adhesion but they do not provide any additional resistance to moisture penetration.

Galvanized Steel

Zinc coating of steel to produce galvanized steel can be produced by hot-dipping the steel into a molten bath of zinc or by electrolytic application in an ionic zinc solution. Galvanized materials are used to provide an additional layer of corrosion protection. The performance properties of the galvanized product produced by hot-dip or electrolytic process are not much different. However, the surface chemical properties do have some significant differences.

Hot-dipped galvanized steel has a spangled appearance, which is determined by the specific chemical composition of the molten zinc bath and the cooling process used for solidification of the coating. The coating has a layered structure that includes a thin layer of alloyed

iron-zinc coating adjacent to the steel interface with a layer of zinc coating proper on the outer surface. Various elemental impurities or additives may tend to segregate to the grain boundaries of the spangles because of their limited solubility in the solidifying matrix, while other elements, such as aluminum, tend to diffuse into the entire surface of the zinc coating.

Hot-dipped galvanized coatings can be used to produce galvanized coatings by sustaining the alloying reaction. The coating is applied at a predetermined thickness and the steel and coating are held at temperatures where the diffusion of iron is very rapid. Diffusion continues until complete alloying has occurred. Galvanized coatings have a matte gray color and low gloss compared to the bright silvery look of the non-alloyed zinc coatings. Galvanized coatings can provide better adhesion for organic coatings without a phosphate treatment than the free zinc coatings.

Zinc coatings applied to steel electrolytically in zinc ion solutions can provide the same corrosion protection and hot-dipped zinc coatings but they are very different in composition and structure. Electro-galvanized steel is comparatively free of the minor impurities that are common to the hot-dipped zinc coatings. In the electrogalvanizing process, there is no need for the metallic element additives that are used to control the behavior of the hot-dipped bath and the spangle size and pattern of the coating. Electrolytic zinc coatings are relatively uniform in composition without the thermally induced diffusions of iron that produce alloy layers in the hot-dipped process. Coating deposition occurs from sulfate or chloride saline solutions so it is possible to have some minor inclusions of these salts in voids of the coating if the surface is improperly rinsed but good control of the rinse process will normally eliminate this problem. Also, since there is no recrystallation from the molten state, there is no variation of the spangle.

Aluminum

Pure aluminum (99.5% Al) has low density, high ductility and low strength. Aluminum can be alloyed to produce metals with many of the desirable characteristics of the pure metal and added properties from the alloy for strength. Aluminum is commonly alloyed with one or more of the elements of copper, manganese, magnesium, silicon,

nickel, tin, and zinc as major constituents and chromium, iron, nickel, silicon, and titanium as minor constituents or normal impurities. Since some alloys may have less corrosion resistance than the pure metal, they are sometimes clad with pure aluminum or another alloy with better corrosion resistance. The various alloys may respond differently to cleaning and treating.

Aluminum alloys are classified into two general types; those which are strain-hardenable and those which are hardenable by heat treatment. These two types are pre-determined by their elemental compositions and how these compositions react to mechanical stress and temperature. Cold working or heat treating of aluminum alloys will develop a more homogenous surface texture and distribution of the various metal elements than the original wrought aluminum. Heat treating of aluminum alloys can affect the chemical responses of their surfaces and the receptivity to cleaning and chemical treatment. For example, a manganese alloy will tend to collect manganese oxides on the surface, in addition to the normal aluminum oxides.

These cold worked or heat treated aluminum alloys will generally have better corrosion resistance than the softer and more heterogeneous wrought material. The raw ingot will have larger, more segregated inclusions while on the treated alloy these particulate intermetallics will be more uniform and less likely to develop corrosion cells.

Manganese, lead, zinc, and titanium have less effect on the corrosion resistance of aluminum alloys than magnesium, iron, silicon, and copper. Different chemical surface characteristics of the alloy will react differently to certain types of exposure. For example, magnesium will retard corrosion if exposed to saline chloride but promote corrosion when exposed to alkalinity.

Aluminum alloys are identified by a series of numbers. Different series of alloys will react differently to chemical treatment. The 1000 series products have the least amount of alloying impurities. These products are readily treated by chemical process and have excellent corrosion resistance. The 2000 series uses copper as the major alloying element to add strength to the metal. They may not always respond to chemical treatment. Since each of the different series will have somewhat different properties, it is wise to know what basic elements are used in the raw material and how they affect pretreatment.

2 Cleaning Processes

The list of metals and their features explains how raw materials have natural surface conditions that interfere with coating adhesion and performance. In the process of being stored, handled and worked they will pick up additional some contamination on their surface. On metals, some of the probable contaminants are oily soils including petroleum products, animal fat, or vegetable oils, deposited during manufacturing operations for rust protection, drawing, machining and forming. There may also be heavy duty drawing compounds and lubrication greases or waxes and some solid soils such as carbon, graphite smuts, metal shavings, polishing products, metal oxides, welding scale, die release products, and red or white oxidation. Removal of soils prior to powder coating is essential to the successful life of the product. It affects the initial adhesion and the ultimate performance in the field.

Soils that are present on metal parts can be removed by a variety of mechanical and chemical methods. What method should be used in a given situation is determined by the part to be coated (size, configura-

tion, material), the type of soil to be removed (dust, wax, oil, salt crystals, etc.) and the performance requirements of the finished product.

Mechanical Cleaning

Soils may be organic substances such as oil or they may be inorganic materials such as mineral type rust inhibitors. Both types of soils can sometimes be effectively removed by mechanically abrading the surface. Mechanical methods, including wire brushing, abrasive blasting, grinding and sanding are used to smooth as well as clean surfaces. Mechanical cleaning using a hand held tool involves considerable labor. Automated processes include vibratory polishing and blasting. Mechanical cleaning is sometimes the only way to remove excessive dirt, rust or scale.

Abrasive Blasting

Blasting with a suitable media can remove dirt, mill scale, rust or previous coatings from a substrate, providing a surface profile that gives good coating adhesion. The blast media will vary dependent on the surface to be blasted and the quality requirements of the blasted product. Typically used media includes sand, steel shot, grit and glass bead. The media is delivered to the part surface at high velocity to impact the soils and cut them away from the metal surface.

The blasting equipment used to deliver the media may be air-blast or turbine-blast. Hand held air-blast systems are very dependent on the concentration of the operator and quality may vary. Blast cabinets are often suction-feed systems that draw particles into the spray gun by induced vacuum and accelerate the media it with a metered stream of compressed air. There are also pressure-blast systems that use a pressurized vessel to deliver the media. Pressure systems are capable of higher nozzle velocity that can provide much faster cleaning of the surface than a suction system.

Blast cabinets' function similar to any booth designed for containment of oversprayed material. Negative pressure within the cabinet is maintained with a fan that draws air into the enclosure through a suitable filter. Typically, this exhaust system will use a cyclone separator to remove the dust and fine particles from the air stream and recover the media for reuse. The scrap material that is separated out of the air-

stream is collected for disposal in a container attached to a dust collector. This scrap material should contain a small percentage of the heavier, reusable media to indicate that the fan pull is sufficient to prevent the build-up of fines in the recovered blast media. A vibratory screener can be added to the process to further refine the recovered material and maintain consistent particle size.

Turbine-blast systems use high-speed turbine wheel with blades. The media is metered to the center of the wheel where it is fed onto the blades, which sling the particles at the surface being blasted. These systems are more energy efficient than air-blast systems because they do not use compressed air for delivery.

Abrasive blasting is most often used for preparation of metal surfaces of heavy structural parts, particularly HRS weldments. It is a very good way of removing the encrustations and carbonized oils that are characteristic of this type of product.

Blasting operations can be manual or automated and they can be installed as part of a conveyORIZED powder coating system or as a batch process. The blasting device may be a nozzle type or a centrifugal wheel type. As previously stated, nozzle blast systems require compressed air for delivery of the media while a wheel system uses centrifugal force. Even though the compressed air is an added cost, it may be necessary to direct nozzles into hard to reach areas of a part. The blast area must be enclosed to contain the blast media and dust.

In addition to cleaning, a blasted surface can create a very good anchor pattern for a coating. Different blast media can be used to vary the profile created on the metal surface. Less aggressive media will remove most soils without cutting too deeply in the metal and leaving a visible texture on the metal surface. More aggressive media can be used to cut stubborn encrustations, such as red oxides, but it will leave more texture on the surface.

A blast system does not require as much space as a spray washer that uses chemical cleaning and it does not generate any wastewater. For these reasons, mechanical cleaning may be the only treatment required for finishes where initial paint adhesion is required. However, mechanical cleaning alone will not provide undercoat corrosion resistance or extend the life of the finished product.

Blast cleaning standards depend on the quality requirements of the surface. Published documents clearly define quality grades of blast-cleaned steel surfaces. Pictorial standards were originally developed by the Swedish Corrosion Committee and later adopted by the Steel Structures Painting Council (SSPC) and other organizations. The principal four grades of blasting endorsed by the SSPC are:

- **White Metal Blast:** Removal of all visible rust, mill scale, paint, and foreign matter. Used for conditions where corrosion resistance is very important and the environment is highly corrosive.
- **Near White Metal Blast:** Blast cleaning until at least 95% of all surface area is free of all visible residues. Used for harsh environments where product is exposed to heavy usage.
- **Commercial Blast:** Blast cleaning until at least two-thirds of the surface is free of all visible residues. For applications where tightly adhering contaminants are allowable on the surface; for products with lower quality standards and non-corrosive environments.
- **Brush-off Cleaning:** Blast cleaning of all except tightly adhering residues of mill scale, rust, and old coatings, exposing numerous evenly distributed flecks of underlying metal. Acceptable in non-corrosive environments where long-term coating life is not expected.

The Swedish Standards Association (SIS) includes very good equivalents of these standards. The British Standards Institute (BSI) also includes very close equivalents of the first three of these standards. The National Association of Corrosion Engineers (NACE) has also devel-

Table 2- Metal Blast Standards

| Degree of Cleanliness | SSPC Standard | NACE Standard |
|------------------------|---------------|---------------|
| White metal blast | SSPC-SP 5 | NACE No. 1 |
| Near white metal blast | SSPC-SP 10 | NACE No. 2 |
| Commercial blast | SSPC-SP 6 | NACE No. 3 |
| Brush of blast | SSPC-SP 7 | NACE No. 4 |

(For additional information on blast cleaning standards: Plaster, H.J., Blast Cleaning & Allied Processes, Vols. I and II, Industrial Newspapers Ltd., London, 1973 and Fuchs, F.J., "Abrasive Blasting Systems," Metal Finishing Guidebook & Directory, Vol. 95, No. 5A, Metal Finishing, Hackensack, N.J., 1997, p49)

oped a set of encapsulated steel coupons that simulate the four degrees of cleanliness.

The texture of a blasted surface will vary with different media. The film thickness of the coating over a blasted surface must be thick enough to cover the peaks and valleys of the pattern created by the abrasion, typically around 1 mil above the peaks of the pattern.

Blast Media

In selecting a specific media it is helpful to understand some of the materials used and how they compare. Blast media can be made of natural material such as silica, sand, mineral sand, flint, garnet, zircon, and other mineral products. It can be made of some natural byproducts such as walnut shell or corncob. And it can be manufactured of a variety of metal and non-metal compositions such as steel, iron, aluminum oxide, silicon carbide, plastic, wheat starch, and glass bead.

In selecting a media, the comparative features that are the most important size of the product, how well it will cut, how well it will recycle and how much it cost. It is also important to know if there are any health and safety issues, such as lung problems associated with silica,

Table 3 – Comparison of Blast Media

| Material | Mesh size (US) | Shape | Density Lb/ft³ | Mohs (hardness) | Friability (break-down) | Init. Cost | No. of Cycles | Per Use Cost |
|-----------------|-----------------------|--------------|----------------------------------|------------------------|--------------------------------|-------------------|----------------------|---------------------|
| Silica sand | 6-270 | ■ ● | 100 | 5.0-6.0 | High | Low | 1 | Med |
| Mineral slag | 8-80 | ■ | 85-112 | 7.0-7.5 | High | Med. | 1-2 | Med |
| Steel grit | 10-325 | ■ | 230 | 8.0 | Low | High | 200+ | Med |
| Steel shot | 8-200 | ● | 280 | 8.0 | Low | High | 200+ | Low |
| Aluminum oxide | 12-325 | ■ | 125 | 8.0-9.0 | Med. | High | 6-8 | Med |
| Glass bead | 10-400 | ● | 85-90 | 5.5 | Med. | Med. | 8-10 | Low |
| Plastic | 12-80 | ■ | 45-60 | 3.0-4.0 | Low/med. | High | 8-10 | Med |
| Wheat starch | 12-50 | ■ | 90 | 2.8-3.0 | High | High | 10-12 | High |
| Corn cob | 8-40 | ■ | 35-40 | 2.0-4.5 | Med. | Low | 4-5 | Low |

■ Angular ● Spherical

and if the media will leave by-products on the surface, such as oils from walnut shells. The chart shows some common blast media and their comparative characteristics.

In addition to the comparative issues listed in the table above, it is a good idea to test different media to have a visual idea of the effect that they will have on the part.

Hard grit media such as aluminum oxide will cut faster and deeper than soft, angular media such as plastic or agricultural grit. Mineral, ceramic, or metallic grit media are used in air-blast systems. Iron and steel media are more often used in turbine-blast equipment.

Materials that are more prone to fracture, reflected in the chart by friability, are not good materials for recycling. Recirculation of these materials will produce wide variations in the surface condition.

Ultrasonic Cleaning

Ultrasonic cleaning combines the chemical cleaning capability of a detergent or solvent solution with the mechanical action of ultrasonic waves. Transducers located at the bottom or sides of the cleaning solution tank generate the ultrasonic waves. The ultrasonic energy causes a cavitation process to take place at the part surface. The agitation of the solution at the part surface creates a scrubbing action that lifts and removes soils from the surface.

Ultrasonic cleaning is used in small systems with a series of immersion tanks. The equipment is fairly expensive but it can enhance the level of cleaning on parts that require special processing. It is often used to process brass parts prior to application of a clearcoat. The ultrasonic waves help remove soils that are hard to get out of the porous surface of the brass.

Parts that are dipped into an ultrasonic cleaner should provide good access to all surfaces to allow the cavitation to work. If parts are grouped too tightly together the process will not be effective.

Vibratory or Tumbling Cleaning Methods

Vibratory systems use an abrasive media in a cleaning solution to remove burrs, rough edges and surface contamination. They are very useful to prepare castings for coating. They will remove the rough-

ness and dried-on compounds that are often present on a cast surface. It is usually a good idea to alkaline clean and phosphate parts after the vibratory polishing so that residual cleaning compound is removed before coating.

Chemical Cleaning

The first step in the chemical pretreatment process is the removal of oils, dirt, and other soils that will interfere with the development of a good quality phosphate coating, good coating adhesion, or cause surface defects. Chemical cleaning can be accomplished by subjecting a part to an aqueous spray or dip cleaner. The cleaner may be alkaline, acidic, neutral, solvent, or emulsion. The particular cleaner used will depend on the soils to be removed, the size and type of part, the type of coating to be applied, and the substrate material.

The mechanisms for cleaning processes are generally recognized to include solubilization, saponification, emulsification, sequestration and deflocculation. In each of these processes the action requires surface wetting of the metal by the cleaning solution. Solubilization, the dissolving of soils into solution, can occur when the soils have very similar polarity and chemical affinity for the cleaning media. Emulsification, the suspension of soils in solution, requires that the soils dispersible in the cleaning media. Saponification, turning the soils into soap, applies specifically to those soils that contain carboxylic acid and ester functionality that can react with alkaline cleaning media. Sequestration involves the deactivation of metallic ions in the soil to prevent them from interfering with the detergent action of the cleaner. Deflocculation is a process that breaks up large particles of aggregate soils into a finely divided material that is held in suspension in the solution to prevent redeposition on the part surface. The last two processes generally operate in conjunction with the first three processes mentioned.

While alkaline cleaners are the most common, there are also acid cleaners and emulsion cleaners used for industrial applications. The cleaner selected must have the ability to remove a wide variety of soils, prevent redeposition, provide cleaning even when contaminated, provide foam control, be easily rinsed and be cost effective.

Proper cleaning of some parts may require a combination of spray and immersion stages. The spray stage combines the chemical properties of the cleaner with the mechanical impingement of the solution applied under pressure. Immersion penetrates areas of the part that may be inaccessible to the spray.

Spray or immersion processes can be used in manual batch operations or in automated systems with overhead conveyor. Batch systems will use a hand-held spray wand or small dip tanks. Conveyorized systems will use an in-line spray washer that has the proper number of stages. Batch systems are suitable for smaller volumes with less stringent quality standards. The list below shows some of the types of hand held systems and how they compare. Larger volumes or products with demanding quality standards will probably require a spray washer.

Spray Wand Phosphatizing – Best suited for large bulky parts where dip tanks or conveyor systems would require more space and cost.

Steam Cleaning – For small volume of heavily soiled parts. Melts grease.

High Pressure Hot Water – Best for cleaning large bulky parts; should have 4-5 GPM, 1,000 PSI plus heat capacity at the nozzle of 160-200 °F (71-93 °C).

Cleaners may be classified according to their pH, a reference to the measurement of the relative alkalinity or acidity. pH is a measure of the ratio of hydrogen ions in solution to the number of hydroxyl ions in solution. If there are more hydrogen ions the solution will be acidic, if there are more hydroxyl ions the solution will be alkaline.

On the pH scale, pure water is neutral and has a pH of 7. A pH of 0 to 7 is acidic and 7 to 14 is alkaline. Caustic soda has a pH of 13 or 14 while hydrochloric acid has a pH of less than 1.

Cleaner pH varies with different products and substrate materials. Cleaner pH will typically range from 4.5 to 10.5.

- alkaline cleaners – mild, pH 9 - 10.5
 - medium, pH 10.5 - 11.5
 - high, pH >11.5
- neutral cleaners – pH 6.5 - 9
- acid cleaners – pH 1.0 - 5.5

Alkaline Cleaning

Alkaline cleaners are the most common method of soil removal for metal preparation prior to the application of powder coating. Cleaners based on sodium hydroxide (caustic) are very economical where cleaning by saponification is desirable. Caustic cleaning media are highly reactive on non-ferrous surfaces and they can cause over-etching on aluminum and zinc surfaces, possibly creating smut and adding zinc to the solution. Caustic cleaning residues are also difficult to rinse away, especially if the solution temperature is in the high range.

Alkali silicates are excellent for cleaners that are used on non-ferrous surfaces. Silicates can provide good cleaning with minimal chemical attack and they do a good job of soil emulsification. They are a little more costly than alkalis and not easily rinsed.

Synthetic detergents and surfactants offer many variations in composition. In some cases they cost a little more than alkalis but they provide a longer bath life which offsets the higher raw material cost. With good performance, easier handling and disposal, and superior effectiveness over a wider array of metals, these products are a good solution for many systems.

Typically, a mild alkaline cleaner (pH of 9 to 10) will provide better soil removal and longer bath life than a high caustic solution. Residues of alkali salts will kill the free acid, drop out metal salts and kill the phosphate bath. A mild alkaline cleaner, prior to the phosphate stage, will aid in the formation of a more uniform, dense phosphate coating, leading to better paint adhesion and corrosion protection.

If the cleaning is not adequate, it is usually better to increase the time in the cleaner rather than the concentration. Two mild alkaline cleaner stages are better than one high caustic stage. Mild alkaline cleaners are good for multiple metals and they can be run at a wide variety of temperatures. A higher pH cleaner may be necessary on occasion for very difficult soils.

An alkaline cleaner is typically comprised of:

- alkaline base
- surfactant/detergent package

- additives for
 - defoaming
 - minimizing attack on substrates
 - coupling agents
- water conditioners

Alkaline Cleaner Component Functions

- **Silicates** - (sodium metasilicate, sodium orthosilicate) High alkalinity, good saponifier and dispersant, softens water by precipitation, inhibits dissolution of zinc and aluminum. May leave a whitish residue on parts if not properly rinsed.
- **Phosphates** - (trisodium phosphate, sodium tripolyphosphate, tetrasodium pyrophosphate, disodium phosphate) Softens water alkalinity, improves rinsing, saponifier.
- **Carbonates** - (sodium carbonate, sodium bicarbonate) Alkalinity, good buffering.
- **Hydroxides** - (sodium hydroxide, potassium hydroxide) High alkalinity, saponifier.
- **Nitrites** - (sodium nitrite) Minimizes oxidation of metal due to cleaner drying.
- **Chelants** - (versene) Softens water, changes form of precipitation.
- **Surfactants** - Provide water/oil solubility. Enables cleaners to work more efficiently by reducing surface tension at the metal surface. Also, prevents part from drying between stages or the spray washer.
- **Defoamers** - Control foam.
- **Inhibitors** - Minimize attack on metal.

The alkaline cleaner is added to water (typically 2 - 10%) and applied hot. Solutions of this type have low surface tension, which means they can easily penetrate beneath and between dirt particles. In addition, the soap or detergent present can often combine with dirt, oil or grease and emulsify them in water to remove them from the surface of the part. When used with pressure spray or mechanical scrubbing, hot alkaline cleaning for 1-2 minutes is a very effective cleaning method.

Surfactants used for cleaners are usually anionic or nonionic, poly-addition products of ethylene oxide and/or propylene oxide with al-

cohol's, amines and phenols. Sometimes the surfactants used in dip cleaners are sulfonates.

The purpose of the surfactants is to break oil and grease from the surface of the parts and emulsify it in the solution. Oils will rise to the surface when the circulation pump is turned off and they can be removed by skimming or overflowing.

A typical spray cleaner stage in a washer is 60 to 90 seconds, while a dip stage may be anywhere from 3 - 5 minutes with temperatures ranging from 120 to 180 °F (49 to 82 °C). Times, temperatures and cleaner concentration vary depending on the cleaner used and the condition of the substrate.

The rinse stage following the cleaner is ambient tap water to remove any residual alkaline cleaner or loosened soil. Rinse stages are overflowed with fresh water as parts are processed.

Cleaning and rinsing alone prior to painting is sufficient as a stand alone pretreatment in a limited number of situations. As with mechanical cleaning, it will provide initial adhesion only and offers no long-term protection.

When cleaning prior to conversion coating, it is important to consider how the cleaner and its effect on the substrate may interfere with the formation and deposition of the conversion coating. Will the cleaner drag-out adversely affect the conversion coating solution? Will the cleaner alter the surface (etching, smutting, etc.)? In a pretreatment process, the cleaner should not be viewed as a separate process but as an integral part of the total pretreatment process that can effect the quality of the conversion coating.

Cleaner Performance Factors

Over time, the soils that are removed from the parts will build up in the cleaner solution. Solid particles will settle to the bottom of the tank as sludge and oils, grease and some floating debris will float on the top of the solution. There is a limit to the amount of contamination that a cleaner bath can tolerate before it will cease to clean and need to be dumped and recharged. Overflowing the solution can help to reduce the accumulation of floating debris but solids can still cause a problem and overflowing the solution will create a need for more chemical. Oil skimming and sludge removal can extend the life of the

cleaner. Techniques for this are explained in the discussion on washer design.

Control Parameters

The parameters for process control of a cleaning solution are process time, chemical concentration, temperature, spray pressure, drain time,

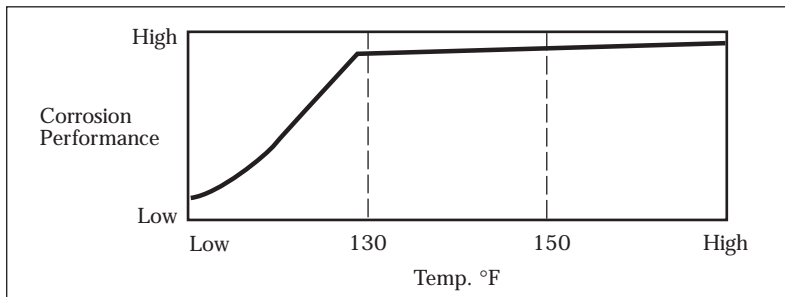


Figure 2-2 - Temperature vs. Corrosion Resistance

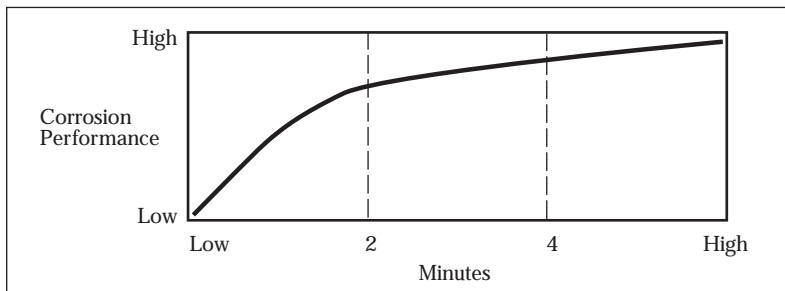
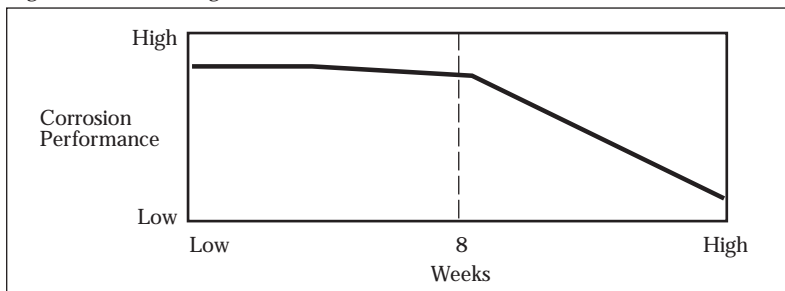


Figure 2-3 - Cleaning Time vs. Corrosion Performance

Figure 2-4 - Cleaning Solution Life vs. Corrosion Performance



and the volume of contaminants in the solution. These are the items that must be monitored, recorded, and maintained within proper ranges in order to achieve predictable cleaning performance. The set of charts shows how some of these control items can affect performance.

There are many variables that affect the length of time that a solution will remain effective, such as the number of shifts, the volume of metal processed, the type of metal processed, and the types of soils removed. This chart shows a typical relationship between time and performance.

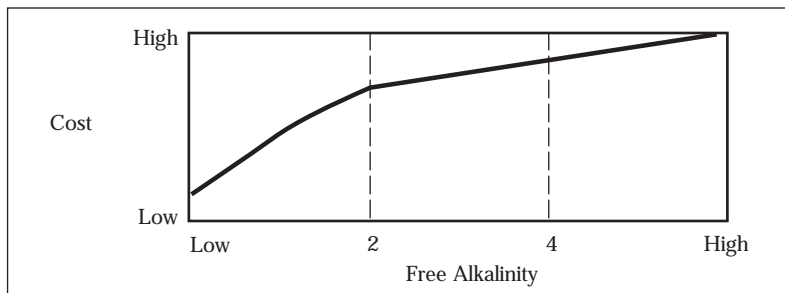


Figure 2-5 – Cleaner Alkalinity vs. Cost

Acidic Cleaning

Acidic cleaning is based on attack of the metal surface by sulfuric, hydrochloric, nitric, phosphoric, hydrofluoric, fluorboric, or chromic acids and the various acid salts of these acids. They generally include a surfactant package, metal ion sequestrants, alcoholic solvents, and an inhibitor to prevent excess attack of the metal. They can be useful for removal of light oxides, organic residues, persistent salts and other soils that are readily dissolved in acid.

Because of the fact that acids are corrosive and therefore more difficult to pump and handle, and because in some cases they are inferior to alkaline cleaners on organic soils, they are much less commonly used. For metals that are prone to hydrogen embrittlement, such as alloy steels and high-carbon grades of steel, acid cleaning is not an option. Acids can also react with some metals to form insoluble byproducts that interfere with subsequent processes.

In a three-stage washer, the first stage combines the cleaning and iron phosphating. These solutions will typically be made up of phosphoric acid, a wetting agent, and an activator.

Acid solutions may also be used to remove scale or oxides in pickling solutions. These solutions are relatively strong mineral acid solutions, using sulfuric, hydrochloric, phosphoric and nitric acid. This type of solution can be useful for removal of stubborn inorganic contamination. One particularly good use is the removal of laser cut scale. Laser cutting of steel will form an oxide layer that is resistant to alkaline cleaning.

Pickling rates increase with higher acid concentration and higher temperature. Excess concentration should be avoided because of the corrosive nature of the solution and the risk of an overly aggressive attack on the metal.

Phosphating

Phosphating, or conversion coating, is the application of an iron or zinc phosphate coating to the substrate. Conversion coating can be a very critical part of the pretreatment process, adding significantly to the performance of the finished coating. A phosphate coating converts the metal substrate to a uniform, inert surface, which improves bonding, minimizes the spread of oxidation if the coating is scratched and improves the overall corrosion resistance of the final part.

A conversion coating can be iron, zinc, polycrystalline, chromate, or manganese phosphate film. They are developed on both ferrous (iron based) and non-ferrous surfaces (zinc, aluminum, terne and manganese). Parts are subjected to an acidic bath and a chemical conversion forms a complete film on the part surface, changing the chemical and physical nature of the metal surface.

Iron Phosphate

Iron phosphate is the thinnest of phosphate films. In the application process, an iron oxide base is developed, followed by a flat or amorphous metal phosphate topcoat. The treated metal surface will typically have a gray to blue iridescent or blue-gold iridescent color, depending on the coating weight and the base metal. A typical iron phosphate consists of:

- phosphate acid base
- accelerators/oxidizers
- surfactant package (optional)

In an iron phosphate solution, the metal surface is etched, releasing some iron into the bath. When metal ions are etched from the part surface, the surface becomes positively charged. The metal ions in the bath are converted to iron phosphate, negatively charged. A pH rise occurs at the interface of the solution and the part, causing the iron phosphate ions to deposit an amorphous coating on the metal surface.

The acid salt content, type and amount of accelerator, and the type and amount of acid etchants varies from one compound to another. These compositions are all moderately acidic. Although crystal site activators are not typically required prior to application of iron phosphate coatings, formulations commonly contain oxidizers and/or accelerators. The oxidizers, such as nitrite or chlorate, act to initiate attack on ferrous parts, providing the iron for the iron phosphate coating. Accelerators, such as molybdate or vanadate, provide active sites for iron phosphate deposition. Choice of oxidizer or accelerator in a particular product may affect the performance or appearance of the final coating.

In a three-stage iron phosphate treatment process, the cleaning and coating are combined by incorporation of a detergent surfactant package in the iron phosphate solution. A source of fluoride ions may be added if aluminum is also being processed to increase the etching effect on the oxide surface of the aluminum.

Iron phosphate coatings can be applied by hand wiping, with a hand-held spray wand, immersion, or a spray washer. The number and type of process stages is directly dependent on finished part requirements. A cleaner/coater combination followed by a rinse is the typical minimum chemical cleaning and phosphating process used. The addition of stages in the process can provide enhanced performance.

The most effective and commonly used method is a multi-stage spray washer. Spray washers are built with as few as two stages and as many as eight.

II

- Two Stage: clean/coat, rinse
- Three Stage: clean/coat, rinse, rinse/seal
- Four Stage: clean/coat, rinse, rinse/seal, DI rinse*
- Five Stage: clean, rinse, phosphate, rinse, rinse/seal
- Six Stage: clean, rinse, phosphate, rinse, rinse/seal, DI rinse
- Seven Stage: clean, clean, rinse, phosphate, rinse, rinse/seal, DI rinse
- Eight Stage: clean, rinse, clean, rinse, phosphate, rinse, rinse/seal, DI rinse

* Deionized water; water that has been filtered to remove negative and positive ions.

| Stages | Two | Three | Four | Five |
|----------------------|------------------|---------------------------|---------------------------|---------------------------|
| Metals Treated | Steel | Steel Zinc Aluminum | Steel Zinc Aluminum | Steel Zinc Aluminum |
| Soils Removed | Average Soils | Average Soils | Moderate Soils | Heavy Soils |
| Degree of Cleaning | Light | Light | Moderate to Heavy | Heavy to Extra Heavy |
| Coating Weights | | | | |
| MG/FT ² | 25 | 25 | 25-45 | 25-90 |
| G/M ² | 0.27 | 0.27 | 0.27-0.49 | 0.27-0.97 |
| Paint Adhesion | OK | Good | Good | Excellent |
| Corrosion Resistance | Low | Acceptable | Acceptable | Good |

Table 4 - Pretreatment Quality From Spray Washers

Phosphate Coating Weight

Iron phosphate is measured in mg/ft², or grams per square meter. Coating weights vary with the different levels of pretreatment. The quality of paint adhesion and corrosion resistance will be affected by the phosphate coating weight. The chart above shows typical results of additional steps in the process.

To determine the coating weight, test panels should be run through the washer with all of the process variables under control. After a clean, fresh panel is run through the washer, it should be removed and tested with the procedure described below. Clean cotton or surgical gloves should be worn to avoid contamination of the sample with skin oils.

Determine the square feet of the panel:

1. Weigh the panel, correct to three places (.000), and record the first weight.
2. Immerse the panel in 10 % chromic acid (CrO_3) in water by weight at 160 °F (71 °C) for 10 minutes.
3. Rinse with tap water or D.I. Water if it is available.
4. Weigh the part again correct to three places and record the second weight.

Then complete the formula:

$$\frac{1^{\text{st}} \text{ wt. in grams} - 2^{\text{nd}} \text{ wt. in grams} \times 1000}{\text{Area in square foot}} = \text{mg./sq. ft.}$$

$$\frac{1^{\text{st}} \text{ wt. in grams} - 2^{\text{nd}} \text{ wt. in grams}}{\text{Area in square meters}} = \text{grams/sq. m}$$

Iron Phosphate Controls

In addition to the number of process stages, the factors that will affect the weight of an iron phosphate coating are time, temperature, concentration, acid consumed (pH), the condition of the substrate and the spray pressure.

- Time in Process - The more time that the chemistry has to work, the more work it will do. The process must be long enough to allow the chemistry to form to a uniform coating on the surface.
- Temperature of the Solution - Soils become more reactive in a heated solution and the chemicals become more aggressive.

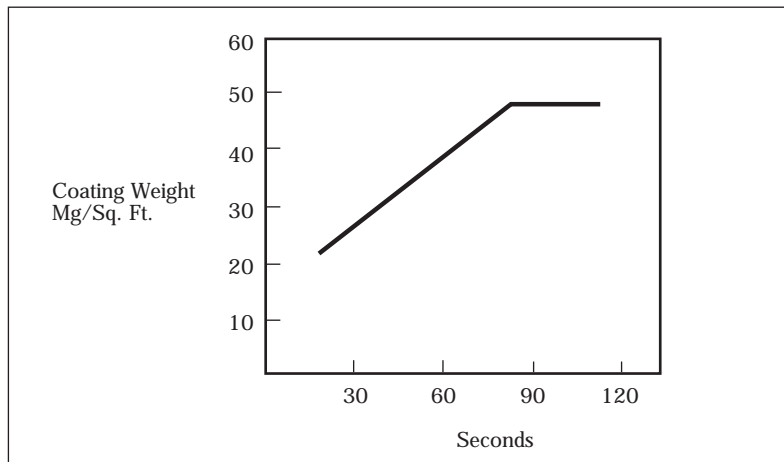
- Concentration - A higher concentration of chemical will provide more total acid, more accelerators and it can provide more coating weight.

Acid Consumed - A higher pH will give less acid and less coating, while a lower pH will give better cleaning and more acid. More acid gives more pickling, providing heavier coatings. Excessive acid can cause too much pickling and the excess acid can dissolve the phosphate coating. The pH that works best for iron phosphate is between 3.5 and 6.0, with most running around 5.0. If the pH is too high (above 6), the parts will not get enough coating weight and they may flash rust. If the pH is too low (below 3.5), the parts will be cleaned and pickled but they will not have any phosphate coating.

The "blueness" of the phosphate coating is related to the coating weight. An iridescent blue indicates a coating weight of 30-35 mg/sq.ft. As the coating weights go up the color will change from blue to blue-gray to gold.

The following graphs show the relationship of each of these control factors to the phosphate coating weight.

Figure 2-6 - Time in Process



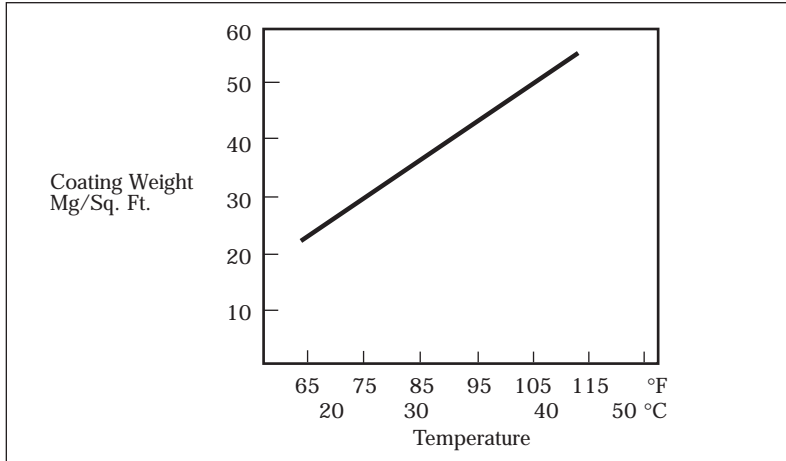
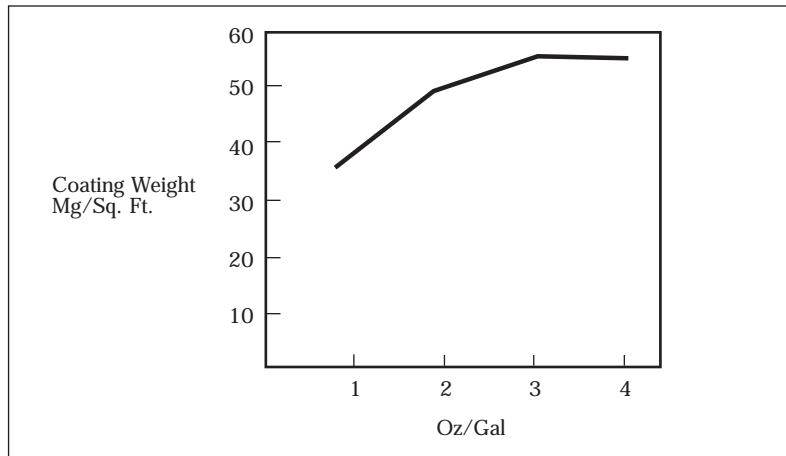


Figure 2-7 – Temperature of Solution

Figure 2-8 – Concentration of Phosphate Chemistry



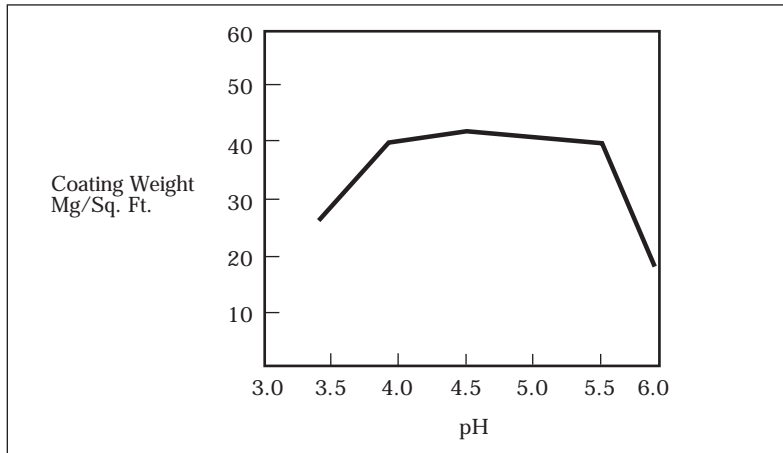


Figure 2-9 - pH of Phosphate Solution

It is also important to maintain consistent control of these variables. Alkaline solutions can be carried into the phosphate solution and cause a rise in pH, or the operators may not make the adjustments to the solution often enough to maintain consistency. This can cause the coating to be spotty in some areas and flash rusting can occur. Solutions should be monitored frequently (3 times per shift) to make sure that they are in good condition.

Zinc Phosphate

Zinc phosphate is a non-metallic, crystalline coating that chemically adheres to the substrate. Zinc coatings are extremely adherent, they provide a uniform coating with improved coating adhesion properties, better coating in recessed areas and better corrosion resistance. A typical zinc phosphate consists of:

- phosphoric acid base
- accelerators
- zinc salts

Zinc phosphate comes from the solution itself, not from the part surface like an iron phosphate coating. Crystals begin forming at anodic

sites on the part surface and stop forming when they hit another crystal. The more origination sites the better the density of the coating. For powder coating, it is best to keep the and densely packed. Powder does not stay in the flow stage for very long. Larger phosphate crystals may not allow the powder material to completely wet the surface and a capillary layer may form under the coating. Moisture will penetrate the coating and cause corrosion that will lift the coating from the surface.

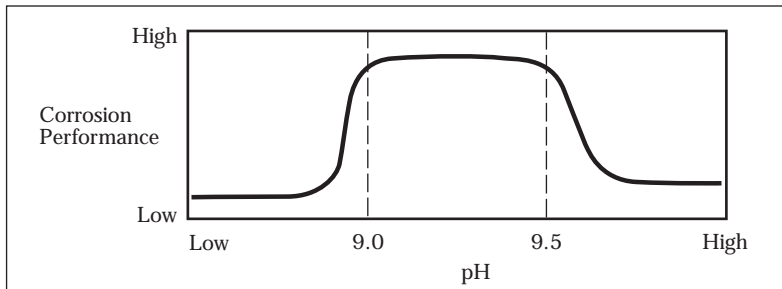
Unlike the iron phosphate, a zinc phosphate can not clean and coat simultaneously in a three-stage process, a separate cleaning stage is required.

Activating (Prior to Zinc Phosphate)

When zinc phosphating, the metal surface is activated by an additive in the cleaner bath or in a conditioning rinse prior to phosphating. Conditioners are mild alkaline suspensions of specialized active titanium salts that adhere to steel, zinc and aluminum surfaces. The conditioner will set up a network of uniform acceptor sites for zinc crystals to deposit. This will increase the number of zinc phosphate crystals, decrease the size of these crystals and generally improve the quality of the zinc phosphate coating. The small crystal size will be more uniform and lower weight, helping to promote adhesion, control the cost of phosphating, and generating less sludge.

Proper pH range, concentration, temperature and bath life are shown in the following series of figures.

Figure 2-10 – Conditioner pH vs. Corrosion Performance



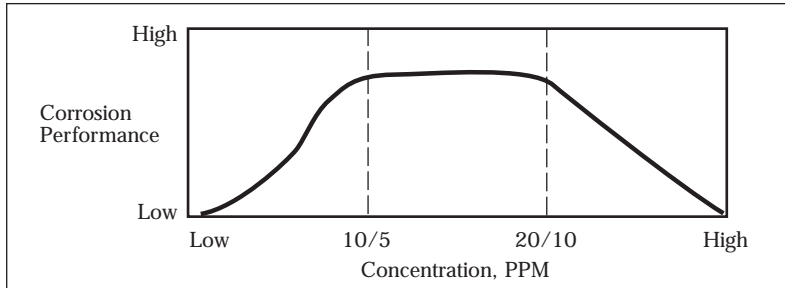


Figure 2-11 – Conditioner Concentrations vs. Corrosion Performance

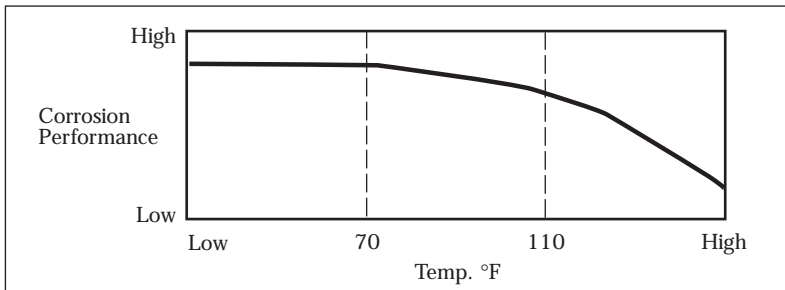
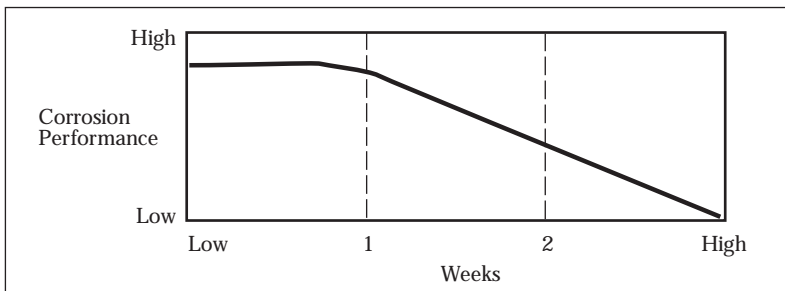


Figure 2-12 – Conditioner Temperature vs. Corrosion Performance

Figure 2-13 – Conditioner Age vs. Corrosion Performance



The crystal size of the phosphate coating has an impact on paint bonding capacity and corrosion resistance. A large crystal structure is more porous, has poorer corrosion resistance, and requires more paint to achieve a complete film. A fine-grained, tight, uniform coating will provide the best performance. The conditioner in the rinse preceding the phosphate stage can assist the development of this fine-grained phosphate coating.

Adding oxidants such as nitrate, chlorate, or nitrite controls the rate of coating formation. The proportion of these various ingredients can control the coating weight and phosphate crystal size. Fluorides are added if aluminum must be processed.

The reactions at the surface of the part during phosphating are:

1. Pickling attack on the metal and oxidation of hydrogen to water
2. Increase of the pH at the interface of the metal and the phosphate solution
3. Over-saturation of the film with coat forming substances
4. Nucleation on the metal
5. Growth of phosphate coating
6. Oxidation and precipitation of iron as sludge

The composition of the bath, the temperature, exposure time and the previous cleaning process will affect the phosphate composition and crystalline phase.

Zinc and polycrystalline phosphate solutions do require more careful attention to produce consistent high quality results. Additions of zinc phosphate and nitrite accelerator to the bath to maintain the proper concentration should be made by automatic feed pumps to ensure good quality and minimum chemical consumption. The improper concentration of these materials that results from bulk adds will produce coatings that are soft, too heavy, and create excessive sludge. If the materials are allowed to run too low, the coating will be coarse and spotty, resulting in poor adhesion and corrosion resistance.

Like other pretreatment processes, time temperature and concentration (total acid, free acid, accelerator and fluoride) will affect the outcome.

Zinc phosphate is the preferred conversion coating used by the automobile industry because of the superior corrosion resistance. The coating is firmly attached to the metal by ionic bonding, the porous crystalline structure provides an extended surface for paint bonding, and if the paint surface is scratched, the inorganic coating protects against corrosion "creepage."

A zinc phosphate solution will continually produce sludge through oxidation of soluble iron to an insoluble state that precipitates. A sludge removal system must be used to provide constant removal of this sludge.

The rinse stage following the phosphate should be ambient tap water. Phosphate salts are more soluble in cold water. The overflow volume should be sufficient to keep the rinse clean and reasonably cool.

Comparison of Iron Phosphate to Zinc Phosphate

From an environmental standpoint, iron phosphate is preferred because it does not generate large quantities of heavy metals that require waste treatment. In some municipalities, an iron phosphate solution can be neutralized and released to drain. Some coaters have waste treatment for iron phosphate and many coating facilities choose to have it waste hauled by a licensed hauler.

Zinc is listed by the United States Environmental Protection Agency (USEPA) in the Resource Recovery and Reclamation Act (RCRA) as a hazardous substance that is subject to waste regulations. It must be treated prior to discharge and the sludge must be waste hauled.

In terms of performance, zinc phosphate with a chrome sealer will typically provide far superior corrosion resistance. Iron phosphate is satisfactory for almost all indoor applications where corrosion resistance is not critical. Zinc is required for outdoor product with superior corrosion resistance requirements. Almost all automotive-specifications call for zinc phosphate.

Table 5 on page II/33 compares the two phosphate processes in more detail.

When deciding between zinc and iron phosphate, the end use of the product is the most important factor. For indoor use in non-corrosive environments, iron will work well and it has several economic and environmental advantages. Zinc will provide the undercoat protection

| | Iron Phosphate | Zinc Phosphate |
|----------------------------|---|--|
| Avg. Coating Weights | 15 to 90 mg/ft ² 0.16 to 0.97 g/m ² | 50 to 500 mg/ft ² 0.54 to 5.4 g/m ² |
| Surface Structure | Amorphous (requires less powder to cover) | Crystalline (requires more powder to cover) |
| Paint Adhesion | Very good (normally will not fracture, even if the metal is bent) | Very good to excellent (crystalline layer may fracture if the metal is bent) |
| Salt Spray Resistance (5%) | 200 to 500 hrs. | 600 to 1000 hrs. |
| Cost in US Dollars | Average \$4.00 to \$8.00 per gal. (one product) | 3 to 4 components needed a. zinc phos. \$8.00/gal b. accelerator \$8.00/gal c. activator \$7.00/lb d. pH adjust \$3-5.00/gal |
| Sludge Formation | Moderate | Heavy |
| Solution Life | Very good | Very good |
| Control of Solution | Very easy to control, 1 or 2 tests, 1 product | Difficult to control, 3 to 4 tests, products must be balanced, pre-conditioning stage must be controlled |
| Equipment | Same as other spray washer stages | Tanks should be stainless steel, sludge separation equipment is needed |
| Maintenance | Minimal | Higher (sludge handling) |

Table 5 – Comparison of Iron & Zinc Phosphate

needed for the more demanding product used outdoors or in highly corrosive environments. The quality of the cleaner and the finish coat must also be considered. Part of the attraction of powder coating is the durability of the film. Good cleaning and high quality powder may allow the use of a less resistant conversion coating.

needed for the more demanding product used outdoors or in highly corrosive environments. The quality of the cleaner and the finish coat must also be considered. Part of the attraction of powder coating is the durability of the film. Good cleaning and high quality powder may allow the use of a less resistant conversion coating.

3 Rinsing

Proper rinsing between process stages is essential to successful pre-treatment. Poor rinsing will leave residues on the part surface that will interfere with the remaining processes. If the alkaline cleaner is not thoroughly rinsed off, it will carry over into the phosphate solution and cause excessive chemical use or poor performance. If the final rinse is inadequate, salts can be left on the part surface and interfere with paint bonding and corrosion resistance.

The rinse following the cleaner should have an aggressive spray pressure to assure removal of all residual alkaline cleaner and soils. The overflow rate is adjusted to keep a degree of alkalinity which helps to avoid flash rust, reduces the precipitation, and ensures more complete rinsing of soaps, fats, oils, grease and surfactants. Some carry-over heat will warm the rinse water, which will improve solubility.

The rinse following the phosphate stage is run at lower pressure than the cleaner rinse to avoid too much disturbance of the freshly deposited phosphate coating. A degree of acidity aids in the removal of unreacted heavy metal phosphate salts. Cooler water may shock off some sludge and stop the reaction between the solution and the metal for reduced streaking. Slight acidity on the surface protects the activity and stability of the final seal rinse.

Both rinses should be overflowed at a rate that will keep them clean enough to do the job, somewhere between 3 and 10 gallons per minute (11.4 to 38 liters per minute). They should be dumped frequently to get rid of any accumulation of contaminants. To avoid excessive carry-over of the chemicals into the rinse water, be sure that the parts and racks are positioned for good drainage and the washer sections are not too close together.

Rinse water in the final rinse should be kept below 300 parts per million (PPM) hardness. PPM can be measured with a Total Dissolved Solids (TDS) meter that will indicate the pounds of a substance dissolved in 1,000,000 pounds of water, or, 120,000 US gallons. One PPM is equal to one milligram per liter (MG/L).

Water impurities can ruin all of the hard work of the coating process and shorten the useful life of the product. Particulate in the water consumes fluoride and produces scale. Organics can produce scale, sludge, foam, and surface defects. Hardness in the water is the chief source of scale, it can kick out soaps and form water spots that will show through the paint or cause adhesion failure. Clean rinse water will help avoid these problems and reduce maintenance requirements to the washer nozzles and plumbing.

Fresh water can be added directly into the rinse tank or through a riser located after the recirculating rinse stage. The added dilution ratio of the residual recirculating rinse water combined with the flushing ac-

tion of the spray reduces the chemical residues to a point near zero. The fresh water riser increases the efficiency of the rinse by a factor of 400+, using the same quantity of fresh water.

Passivating Rinse/Seal

Proper final rinsing is critical to the success of the coating. Poor rinse water quality can easily lead to adhesion failure or rapid corrosion in the field. Water rinsing only removes the active chemicals (acid) left on the metal surface. Unreacted chemicals left on the surface can cause corrosive conditions under the finish coating. The rinse seal neutralizes any residual water-soluble salts to prevent humidity blistering and removes any unrinsed phosphating solution residue. It stabilizes the surface pH to prevent alkaline undercutting and leaves the surface slightly acidic, sealing voids in the coating. A pH of 4.0 to 5.5 eliminates carbonates in the water and prevents the possible precipitation of metal hydroxides. The final rinse water should be kept below 100 parts per million (combined) of chlorides and sulfates.

Historically, these rinses were dilute chromic acid solutions in water. Intense ecological pressure has driven a demand for non-chrome rinses that will provide the same corrosion protection and some of them perform quite well. In many cases, a non-chrome rinse is most effective and a specific substrate but not as effective for a broad range of substrates. However, in cases where the product does not need an exceptional level of corrosion resistance, the non-chrome seal rinse is the best choice. Chromic rinses still provide the best results over a broad variety of parts and operating conditions, especially with zinc phosphate. On products that require exceptional corrosion resistance the chromic rinse is still superior.

Humidity testing can be used to determine the overall quality of the pretreatment process. Massive adhesion failures in humidity test are often the result of a poor final rinse. General blistering can also show problems related to final rinse water quality. Many times an early failure in salt spray testing is the result of poor final rinse. In salt spray the rinse can be identified as the cause of adhesion failure when the failure occurs early in the cycle without significant corrosion on exposed surfaces.

Reverse Osmosis or Deionized Water Rinse

The rinse/seal is frequently followed by a deionized water (DI) rinse to remove any accumulation of the seal rinse or phosphate, which might impair coating adhesion or performance. DI water system filters the positive and negative ions from the water to create pure water with not mineral content.

Phosphate residue on the metal surfaces can cause uneven coating film deposition and adhesion problems. DI rinsing will eliminate mineral spotting, corrosive salts, mineral humidity blisters and organic particulate that can cause surface defects.

The DI rinse includes a recirculated spray zone followed by a fresh DI halo in the exit vestibule. The DI water in the recirculation tank should not exceed 50 micromhos conductivity and the fresh DI make-up water supplied by the halo should not exceed 10 micromhos.

Reverse osmosis (RO) purifies water by using pressure to force it through a membrane, which will not pass dissolved salts. RO is only slightly less effective than deionization and the equipment is typically less expensive to purchase and maintain.

Typical Spray Washer Processes

The 3-stage iron phosphate washer is commonly used for applications that do not treat heavily soiled parts. The 3-stage iron phosphate process combines the cleaning and phosphating steps in a single stage, reducing pretreatment costs and requiring less space. Cleaner solutions are usually alkaline while the phosphate solutions are acidic. The 3-stage washer must compromise the two processes, producing less than perfect results. Much better cleaning and phosphating is accomplished when these processes are separate with rinses in between. Separating the cleaning and phosphating allows the processes to be adjusted for maximum benefit of each process. The result is much more complete cleaning and a more uniform and complete phosphate coating. Some typical stages of process for spray washers are shown on page II/37.

| | |
|---|--|
| • Three Stage Iron Phosphate | |
| Stage 1 - Clean/Phosphate | - 90 seconds at 160 °F (71 °C) |
| Stage 2 - Rinse | - 30 seconds at Ambient |
| Stage 3 - Rinse/Seal | - 30 seconds at 120 °F (49 °C) |
| • Five Stage Iron Phosphate | |
| Stage 1 - Alkaline Cleaner | - 90 seconds at 160 °F (71 °C) |
| Stage 2 - Rinse | - 60 seconds at Ambient |
| Stage 3 - Iron Phosphate | - 60 seconds at 140 °F (60 °C) |
| Stage 4 - Rinse | - 30 seconds at Ambient |
| Stage 5 - Rinse/Seal | - 30 seconds at 120 °F (49 °C) |
| • Seven Stage Zinc Phosphate | |
| Stage 1 - Alkaline Cleaner | - 90 seconds at 160 °F (71 °C) |
| Stage 2 - Rinse | - 30 seconds at 110 -120 °F (43-49 °C) |
| Stage 3 - Activating Rinse | - 30 seconds at Ambient |
| Stage 4 - Zinc Phosphate | - 60 seconds at 140 °F (60 °C) |
| Stage 5 - Rinse | - 30 seconds at Ambient |
| Stage 6 - Chromic Seal | - 30 seconds at 120 °F (49 °C) |
| Stage 7 - D.I. Rinse | - 30 seconds at Ambient (Recirculated) |
| With a fresh D.I. halo in the exit vestibule. | |
| • Eight Stage Iron Phosphating - Dip Spray | |
| Stage 1 - Immersion clean | - 2 minutes at 150 °F (66 °C) |
| Stage 2 - Spray clean | - 1 minute at 100-150 °F (38-66 °C) |
| Stage 3 - Spray rinse | - 1.5 minutes at 100-150 °F (38-66 °C) |
| Stage 4 - Immersion rinse | - 0.5 minutes at 140 °F (60 °C) |
| Stage 5 - Immersion phosphate | - 2 minutes at 140 °F (60 °C) |
| Stage 6 - Immersion rinse | - 0.5 minute at 140 °F (60 °C) |
| Stage 7 - Spray chromic rinse | - 1.5 minutes at 100-150 °F (38-66 °C) |
| Stage 8 - Deionized-water rinse | - 0.5 minute at Ambient |

Some Typical Spray Washer Configurations

Dip vs. Spray Methods

Many cleaning and surface conversion methods can be used with either dip or spray techniques. Each of these methods has advantages and limitations.

Dipping has the advantage of reaching recesses and other areas of the parts, which might not be accessible to spray. Pockets of trapped

air, however, can cause problems for dipping methods. They can prevent the entry of cleaning solution into recesses and, in extreme cases, make it impossible to submerge a part. Good temperature control is usually easier with dip methods because a single large volume of liquid is involved. Heat is lost more quickly when warm liquids are sprayed in cooler air.

An important point to remember: in a dip process, any residue that remains on the surface of the cleaning solution or rinse solution will be redeposited on the part as it is withdrawn from the dip tank. To help prevent this, a spray rinse is recommended.

Spray methods are able to use the impingement energy of the spray to help dislodge dirt and sprayed liquid can often be directed into recesses that contain trapped-air pockets. Spray techniques may also use small volumes of liquid, which may be an advantage. Spray nozzles must be properly maintained to perform correctly and avoid clogging or other problems that will lead to a poor spray pattern and reduce effectiveness of the process.

Both dip and spray methods require pumps for circulation, filters and related plumbing. Both require close monitoring of temperatures and chemical concentrations and both are subject to gradual or sudden contamination.

In some cases, a combination of dip and spray is required to provide the complete cleaning of the part. Car bodies are frequently pretreated this way.

Washer Design

The exact number, type and sequence of treatment stages for the washer is determined by the quality requirements with input from the chemical supplier and equipment manufacturer. The desired level of quality for the end product must be expressed as a specification. (UV Resistance, Salt Spray Hours, etc.) The specification is then used to determine what pretreatment method will be used.

The basic components of the washer are tanks, pumps, spray nozzles and a tunnel to contain the process. Heaters, valves, gauges, etc. are added for control. The solution is circulated from a tank by the pump, through the nozzles and onto the parts, then returned to the tank, or, the part is submerged into the tank.

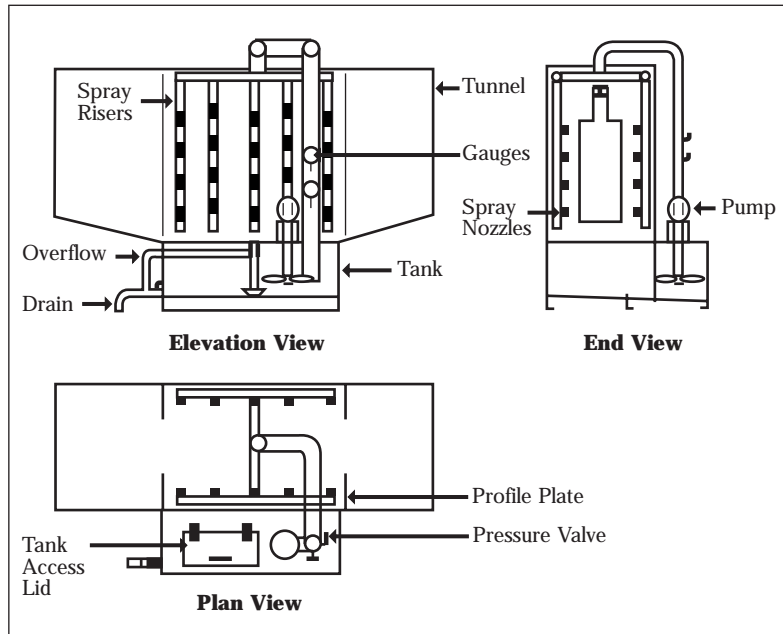


Figure 2-14 - Spray Washer Components

An understanding of the pretreatment system, materials, design and controls is very important to the finishing system operator.

Solution Tanks

The solution tank for a spray stage will usually be approximately the same length as the process zone. The process zone is determined by multiplying the required process time by the design conveyor line speed. In width, the tank will extend beyond the tunnel from 30 to 40" as required for the tank access lids and pump mounting plate. The tanks should be between 36 and 42" in depth to allow for the depth of the pump and enough space to keep the pump up off the floor.

Solution tank sizes are based on the ratio of their capacity in gallons to the theoretical gallons of solution pumped per minute. It is recommended that this ratio be three times the pump capacity. These volumes are actual solution volumes and allowance must be made for heating coil displacement when an internal heat exchanger is used.

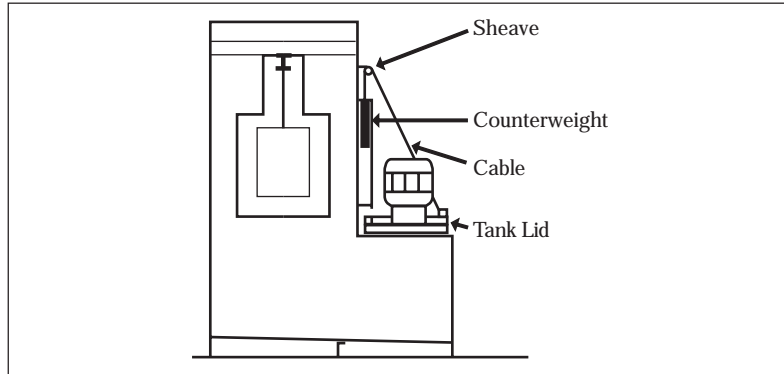
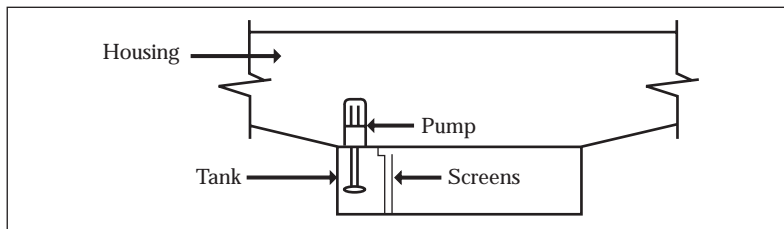


Figure 2-15 – Tank Lid With Counterweight & Pulley

As previously stated, the tank should extend outside the housing far enough to allow for a screen chamber, overflow, and pump well. The tank extension should be fitted with hinged, vapor-tight covers with lifting handles to provide operator access to the solution. Where the covers are too large for easy operation, sheaves, steel cables and counterweights should be used (Figure 2-15). Each tank should be equipped with a flush mounted drain and a removable clean out door on the face for heavy maintenance.

Pump screens should be installed to isolate the pump inlet from gross particulate that could be passed to the nozzle and cause plugging. Guide plates and bars should be installed for double screening at the pump well. A single pocket for two screens should be provided so that a cleaned screen can always be slipped in back of the screen still in place. The surface area of the screen should be a minimum of one square foot per 100 GPM of solution pumped. Screen area larger than this ratio will not require cleaning as often.

Figure 2-16 – Pump Screens



Pump screens for the phosphate tanks should be Type 304, 18-8 stainless steel wire, 18 gauge, 6 mesh, with edges framed and stiffened by bent strips made of 16 gauge 18-8 stainless steel sheet metal and spot welded as required. All other process tank screens can be made of 16 gauge galvanized steel wire but stainless steel is preferred. The tops of the screens should rest against the side of the overflow gutter and should be below the solution operating level so the tanks can be overflowed into gutters without screen interference. The screen handles should extend above the solution level. This screen arrangement allows the operator to remove and clean one screen at a time during operation without exposing the pump to unfiltered solution.

The tank bottom should be sloped, 1" of drop per 5'-0" of tank width, towards the drain and clean out door, with proper structural support underneath.

Drainage Spaces

The drain space is the distance from the center of the last spray pipe in one group of sprays to the center of the front spray pipe of the next zone. Sufficient space must be allowed between spray zones to guard against mixing of solutions by over spray or drainage from work being processed.

Drain times, are determined by the shape and size of the parts and the manner in which they drain. In all cases, drain time should be kept as short as possible to prevent drying of work between spray zones. The length of drain zone is determined by drain time and conveyor speed. Usually the drain time will be 30 to 60 seconds.

The drain zone must be long enough so that a part or rack of parts is never entering a process stage while the tail of the part is still in the previous stage. For example, if the parts to be run are 10'-0" long and the line speed is 8 FPM, a 60 second drain zone would be 8'-0", allowing the part to extend into two stages at the same time. This would produce an unacceptable amount of cross contamination. However, when the drain zone is extended beyond 60 seconds, misting nozzles should be installed in the drain zone to prevent the part from drying. If the part dries out between stages the surface may begin to react with moisture and oxygen to form flash rust. One riser can be mounted in the drain area with a set of misting nozzles that deliver a

low volume of fresh water. This helps to rinse the part and keep it from drying out and flash rusting.

The length of inlet and exit vestibules for the conveyor should be long enough to prevent vapor roll out or excessive dripping from exiting parts. Since the parts will still be dripping as they exit the washer, it is a very good idea to install a drain trench directly under the conveyor for a few feet to prevent water accumulation on the floor.

The drain deck should be sloped with 70% of its length angled back to the spray zone being exited and 30% of its length angled to the next spray zone.

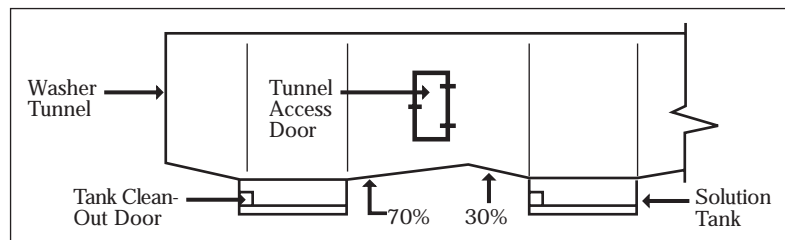


Figure 2-17 – Drain Zones

Tank & Housing Materials

The solution tank and the washer housing should be made of sheets and assembled as all welded construction complete with all necessary structural steel stiffener members and support steel. Bolted and gasketed construction is not recommended because it is almost impossible to avoid leaks.

With mild steel construction, the cleaner tank and rinse tanks are generally made of 1/4" thick plate, while zinc phosphate solution tanks are made of at least 3/8" plate.

The housing shrouds, conveyor splash guards, drip shields and vestibule ends, including floors, should be constructed of not less than No10 gauge sheet steel, and floor plates in drain spaces or over open tanks should be of 3/16" steel plate. The zinc phosphate treatment zone housing 3/16" steel plate. All necessary angles, structural steel shapes, or flanged edge sheets for housing reinforcement and conveyor support should be provided throughout the equipment. If stainless steel is used, all materials can be one gauge lighter.

Stainless steel, either type 316 or type 304, has always been recommended for D.I. Water Rinse, chrome rinses, and Zinc Phosphate. Recently, there is increasing interest in using stainless steel in other parts of the washer. Cleaner stages, tunnels, conveyor shrouds, and whole washers are being built of stainless steel.

The washer is less likely to contaminate work in progress, it is corrosion resistant, and another important advantage, is easier maintainable. The surface remains smooth and does not flake or chip like mild steel, so screens stay cleaner, solutions stay cleaner longer and nozzles do not plug as easily. Long term repairs or replacement of shrouds, profiles, and screens is eliminated. Also, with some companies there is increasing emphasis on clean, high quality, appearance, and the stainless steel surface provides a this.

Building a washer of stainless steel will add a lot of cost. There are many variables, such as washer size, total project size and how much of the washer is stainless steel; the tunnel, drain decks, tanks, plumbing or the whole machine. A complete stainless steel washer will add 40% to 60% to the cost. Also, welding dissimilar metals can produce galvanic corrosion, so the mixing of SS and MS can be a problem.

Another alternative material to mild steel is composite fiberglass. It offers excellent corrosion resistance and a very cleanable surface with good appearance. The fiberglass material is molded in sections and fastened together. Some early versions of composite washers were prone to leak but more recent designs have resolved the problems that caused this and they are typically a very sound method of construction. Field visits or other research is recommended to see the methods of construction and confirm that the design is leak proof.

Another material that can be used for washer construction is polypropylene. It can be welded to provide a leak proof washer and the tunnel will allow some light to penetrate to the interior. The tanks will typically be 3/4" thick material, providing some insulating capacity. Like SS or fiberglass, the polypropylene surface will not corrode. The tunnels and walls are reinforced with steel to avoid sagging or stress fractures.

An expanded metal or fiberglass walkway should be provided throughout the length of the washer with suitable structural support. It should be as wide as possible to protect workers from stepping off the edge

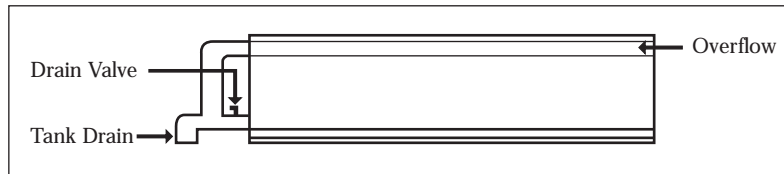


Figure 2-18 – Tank Drain and Overflow

and to keep parts from falling into the tanks. It should cover the drain decks as well as the area over the tanks so that there is little danger of slipping inside the washer during maintenance work.

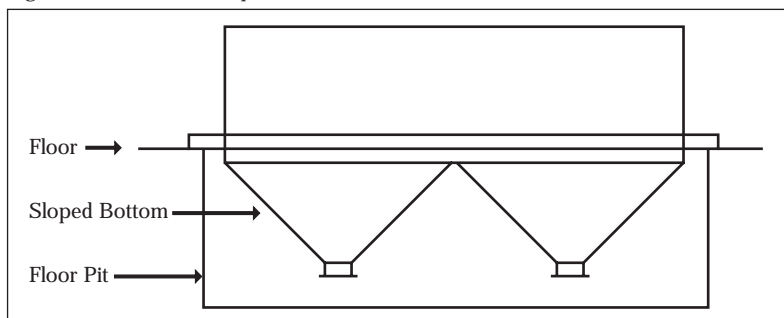
The tank drain connections should be large enough for rapid draining. In normal installations, a 2" overflow gutter drain and a 3" tank drain from the sump in the tank bottom are standard practice. The tank drain should be flush mounted or split nipple and fitted with a valve close to the tank. The overflow gutter drain line should be connected to the tank drain line outside the drain valve.

Zinc Phosphate Tank

Zinc phosphate solutions are corrosive and they generate a lot more sludge than an iron phosphate solution. Because of this, it is necessary to use thicker material or stainless steel in the zinc tank, and provisions must be made for sludge removal.

The zinc tank bottom form should be designed to provide for easy removal of sludge through a permanent suction line to the transfer

Figure 2-19 – Zinc Phosphate Tank



pump, or through a suction hose and sweeper type hand tool. Heating coils and pumps should be kept well above the tank bottom.

Sludge Removal Tank

Zinc phosphate solutions will generate sludge that must be removed. A sludge settling tank should be located on a structural steel frame convenient to the zinc phosphate solution tank. The tanks are connected with piping and a transfer pump for periodic transfer of sludged solution from the process tank to the settling tank.

The sludge settling tank may be square or round and should have a sloped bottom, of approximately 30 degrees from the vertical. Tank capacity should be at least 1/3 the working volume of the zinc phosphate solution tank.

The settling tank should have a safety overflow line back to the phosphating solution tank and a valved draw-off line located in each cone section and connected into the overflow line for returning the clear solution to the solution tank. The draw-off should be located so that approximately 40 gallons of solution can be held in the cone bottom below the draw off line.

The bottom of the cone should be fitted with a 4" dump valve for sludge removal. The tank should be elevated high enough above the floor level to allow a barrel or suitable container to be placed under the dump valve for sludge removal, and also to provide for gravity return of the clear solution to the phosphate solution tank.

Access Doors, Ladders & Lighting

Doors are built into the housing walls between the spray zones to provide access for maintenance workers or operators to view the spray zones while in operation. The area around the tunnel access door is one of the first places to rust so the door should be constructed with a vapor tight fit and rugged hinges and latches.

Solutions will drip off the bottom of the door when it is opened. To prevent the drips from running down the outside of the washer and corroding it, a drip trough should be attached to the tunnel under the door with a few small holes to allow the solution to run back into the washer.

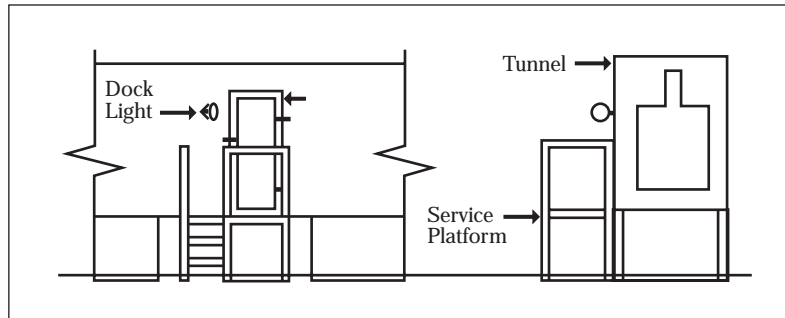


Figure 2-20 – Access Door With Service Platform & Dock Light

Steel ladders, at each access door, and at the ends of the housing, can be installed for easy access to the inside of the washer. The best design includes a platform and a dock light to illuminate the washer interior.

Equipment Exhaust System

In the ceilings of the end vestibules, sheet metal vent stacks are installed to exhaust outside of the building, causing room air to flow into the ends of the machine and up the stacks and preventing equipment vapors from escaping into the room. A drip shield is installed under the stack to prevent condensation from the stack from dripping on the work.

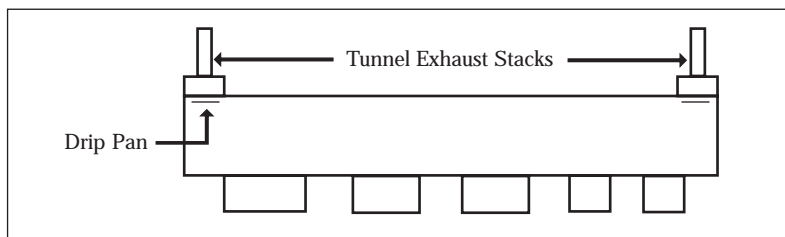


Figure 2-21 – Tunnel Exhaust

Conveyor Splash Guard

A splash guard should be installed around the monorail track, trolleys, and chain for the full length of the machine, to prevent the spray from

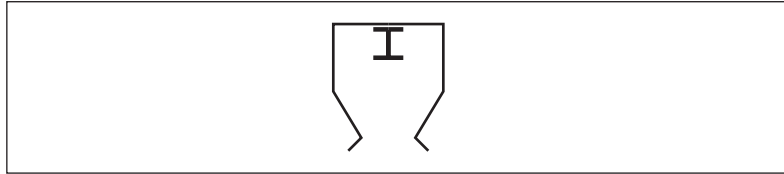


Figure 2-22 – Conveyor Splash Guard

reaching conveyor parts, mixing with lubricating grease and oil and then falling on cleaned and processed surfaces of the work going through the system.

Water vapor around the washer roof can cause rapid corrosion of the conveyor splash guard and conveyor rail. It is a good idea to construct the shroud and the conveyor rail inside the washer of type 304 stainless steel.

Some washers are built with the rail mounted outside of the washer with a slot in the washer roof for the hanger. This helps prevent moisture from removing chain lubricant and reduces chain rust. If the washer is made of stainless steel this is good construction. If it is made of mild steel the vapors that escape the conveyor slot will condense on the washer roof and cause severe rust to occur.

Pumps

Solution pumps are typically standard side suction, centrifugal type, with open impeller and with double bearing shaft supports for direct connection to the drive motor. Pumps with enclosed type impeller are sometimes used, but experience, especially in handling phosphate solutions, indicates that this type of pump requires more maintenance and does not maintain volume delivery and head pressure as well as the open impeller type pump. Barrel mounting type pumps are recommended for dependable performance and ease of maintenance. Horizontally mounted pumps are not recommended.

Solution pumps for cleaner and all rinses, except a chromic acid rinse, can be of all iron construction unless otherwise specified. Zinc phosphate solution pumps should be of non-corrosive materials, preferably type 304 stainless steel. Pump sizing is based on pumping solutions at the specified temperatures for the particular solution with

normal allowance for head losses in piping, fitting and valving arrangements.

Piping

Standard weight steel pipe and cast iron fittings can be used throughout the washer for all equipment piping. Schedule 80 CPVC is also excellent for washer interior plumbing but there is some concern where heated solutions will be run. Temperatures in excess of 140 °F (60 °C) can cause CPVC to sag. Stainless steel is acceptable for any stage but may be cost prohibitive.

Zinc phosphate solutions, chrome rinses and DI or RO water should have type 304 stainless steel or schedule 80 CPVC.

Directional turns should be held to a minimum in all piping to reduce line pressure losses as much as possible. Piping is sized to deliver the required amounts of solution and to maintain recommended pressures at the nozzles.

The spray headers should be supplied near the centers of the manifold, feeding both ways rather than from one end and they should be of the same size pipe full length, with no reduction in size for volume delivery control.

Top headers and drop spray pipes are typically preferred. When bottom headers and vertical spray pipes are used, the bottom headers should have valved ends so the lines can be thoroughly flushed. The installation should be made for easy removal for cleaning.

In the phosphate spray zone, a transition fitting should be installed directly on top of the pump discharge, to make the pipe line to the headers at least one pipe size larger than the pump discharge pipe size.

Risers

The risers are mounted vertically in the spray zones, supplied from a header, with nozzles that spray onto the work in progress. Typically, risers will be installed on 12" horizontal centers with a stagger pattern of nozzles on 12" vertical centers. As the conveyor increases in speed it is possible to increase the spacing of the risers. The following table gives a guide for spacing of the risers at various line speeds.

| Conveyor Speed FPM | Tap Spacing in Headers (approx.) |
|-----------------------|-------------------------------------|
| 3-10 | 12" |
| 10-13 | 14" |
| 13-16 | 15" |
| 16-20 | 17" |
| 24 | 18" |

Table 6 – Riser Spacing

Nozzles

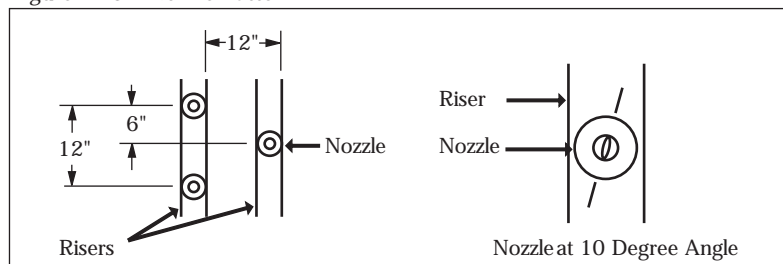
Glass reinforced polypropylene, clamp-on type nozzles are recommended. They are easier to clean, change and adjust than threaded steel nozzles.

In most cleaner and rinse stages a 50-50 flat spray nozzle is best. Nozzle sizes, such as 50-50, refer to the GPM of output and fan spray angle at 40 PSI. A 50-50 nozzle will spray 5.0 GPM at a 50° spray angle at 40 PSI. The output and spray angle will change at lower pressures.

Nozzles are mounted in a staggered pattern to provide good impingement on the entire work surface. Fan spray patterns should be adjusted on a 10° angle from vertical.

Nozzles near the end of the process stage should be adjusted in slightly to help prevent carry over into another stage.

Figure 2-23 – Nozzle Pattern



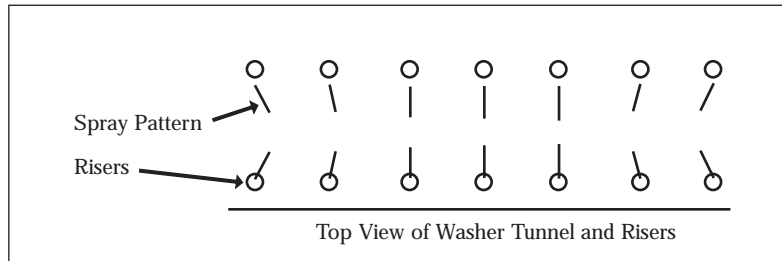


Figure 2-24 - Nozzles Adjustment

In the phosphate section a hollow cone type nozzle should be used. A flooding type nozzle should be used in a final D.I. halo rinse and most chromic final rinses where high impact pressure can remove coating.

Typical Nozzle Volume and Pressures:

- Cleaner and Rinses, 4 to 5 GPM at 15 to 20 PSI
- Iron Phosphate, 2.8 GPM at 10 to 15 PSI
- Zinc Phosphate, 5.0 GPM at 10 PSI
- Misting Nozzles (for wetting in drain zones), flooding type, 0.5 GPM at 10 PSI.

Note: It is good practice to connect the last riser in a rinse stage to a fresh water supply and use it as make up water for improved rinsing. A flow meter and valve attached to the inlet provides very accurate control of the overflow rate.

Water Conservation

It is very important to minimize water consumption, especially if waste treatment is necessary. Even if water is comparatively inexpensive for an operation now, chances are this will not always be the case and it makes sense to conserve water and chemicals. Several methods of water conservation can be incorporated into your washer.

Counterflow of the rinse stages from the last rinse back toward the preceding stages is one popular way of saving water. The proper way to do this is to attach a pipe from the discharge of the final rinse, plumb it to the preceding stage and connect it to a pair of risers with nozzles that have a very low flow rate, 0.3 to 0.5 GPM

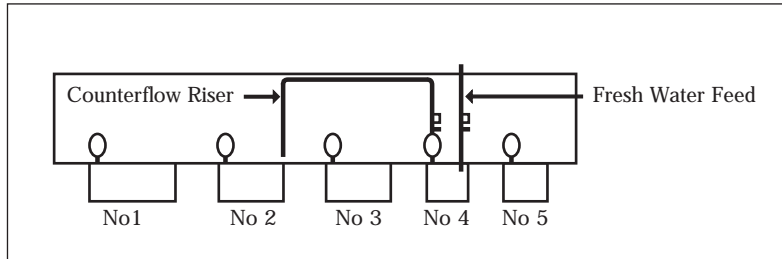


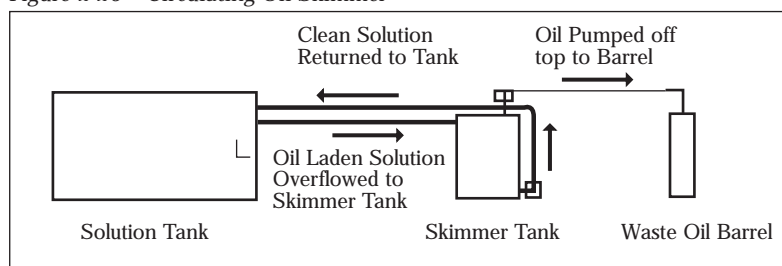
Figure 2-25 – Counterflow Rinses

This set of risers will spray the parts as they exit the process stage, providing extra rinsing, and the overflow will drain to the process tank as make up. Fresh water will be introduced to the final rinse to make up for this overflow to the preceding stage. The make up pipe and the counterflow pipe should be equipped with a flow meter and manual ball valve to regulate the volume. This counterflow method makes the final rinse the cleanest water and reuses overflowed water. The chemical supplier can suggest the proper stages to overflow and what volume.

Another method of conserving both water and chemical is an oil skimmer in the cleaner stage. Oil skimmers are available at a relatively low cost and they can significantly increase the life of the cleaner bath. Belt type oil skimmers do not perform very well in pretreatment solutions. A circulating system that separates the oil and returns the solution back to the tank can work very well. The skimmer tank is small, around 500 gallons and sits right next to the solution tank.

Another thing that can reduce the life of the cleaner bath is a build-up of solids in the solution. To keep the volume of solids in the cleaner

Figure 2-26 – Circulating Oil Skimmer



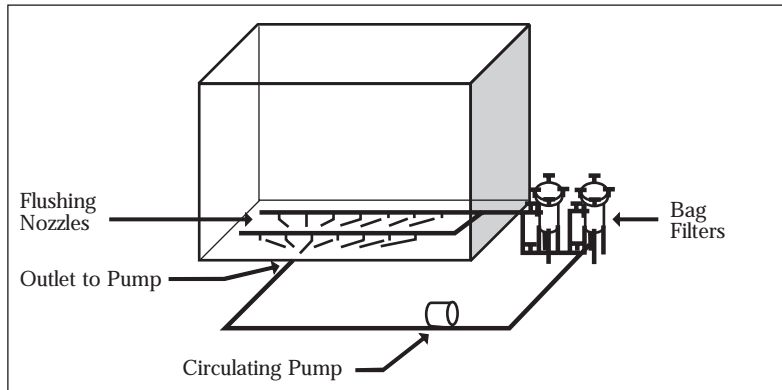


Figure 2-27 – Bag Filter Circulation System

tank to a minimum, a bag filter can be used. Bag filters can be installed in the discharge line coming from the solution circulating pump or they can be installed with a separate circulating pump. The circulating pump pulls the solution out, passes it through the filter to remove the solids and returns it to the tank.

Solids will settle on the floor in the form of sludge. The outlet to the bag filter may not have sufficient force to pull from the entire tank floor. The most effective way to remove solids from the tank is to use a separate circulating pump and a flushing arrangement. In this arrangement, a series of pipes is located near the floor of the tank with a series of nozzles or eductors mounted along their length. Solids are flushed along the floor of the tank towards the outlet by the rows of eductors. This provides more complete removal of solids from the tank. The piping and pump will add cost to the installation and it may not be practical for lower line speeds (under 15 FPM) with smaller tank volumes.

The size of the filter media should not be below 200 micron. Very small particulate will quickly load the filter and plug it up. Dual bag filters are often used to make the system more efficient with less frequent cleaning. The first filter is around 500 micron and the second is around 200 micron. In this way the first filter can remove the grosser sized particulate and the second filter can catch the finer particles. Valves are installed on each side of each filter so that they can be isolated from the flow and cleaned without turning the pump off.

Gauges should be attached to the discharge pipe of the solution circulating pump leading to the manifold to allow monitoring and adjustment of the pump pressure and the solution temperature. A high quality, liquid filled, pressure gauge should be used for long life and accurate output. A valve is installed in the discharge pipe to control pressure.

Solution Heating

The heating of a solution is one way to enhance performance. Solutions are generally heated by steam coils or by an internal heat exchanger with a gas burner. With any system of solution heating, automatic heat control must be provided.

It is important to use an efficient design and to maintain it in good working condition to avoid excessive operating cost and ensure the correct temperature. To be sure that the heat exchanger is properly maintained, heating surfaces should be designed and installed to allow access for cleaning of the tanks and heating surfaces.

Many commercially available heat exchangers are poorly suited to perform efficiently in a spray washer solution. Steam coils or immersion tubes of a very specific design should be used to provide the performance required.

Immersion Tubes

Immersion tubes should be serpentine tube bundles with manufactured long radius weld elbows and returns for maximum energy efficiency. This will provide the best possible efficiency and lowest maintenance. Heat exchangers with sharp corners or mitered joints will not perform as well and they will wear out much sooner.

The gas burner fires into one end of the tube and the gases exhaust from the other end.

Some manufacturers run the exhaust pipe from the immersion tube inside the washer tunnel. This will prematurely rust the surrounding area, adversely affect the pretreatment process and cause damage to CPVC plumbing. The correct design is to run the exhaust pipe outside of the tunnel and insulate it to avoid danger to personnel.

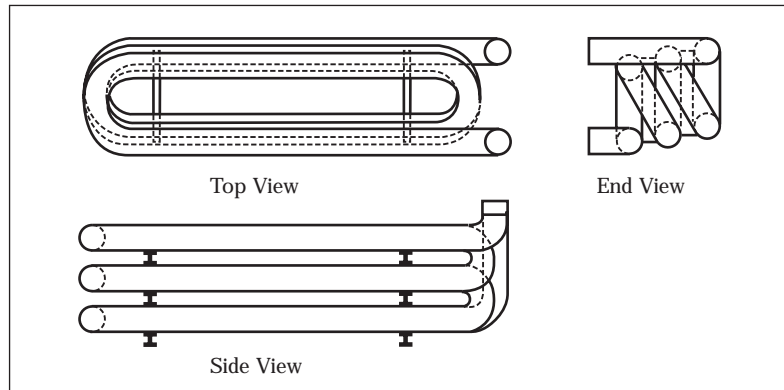


Figure 2-28 - Six Pass Immersion Tube Bundle

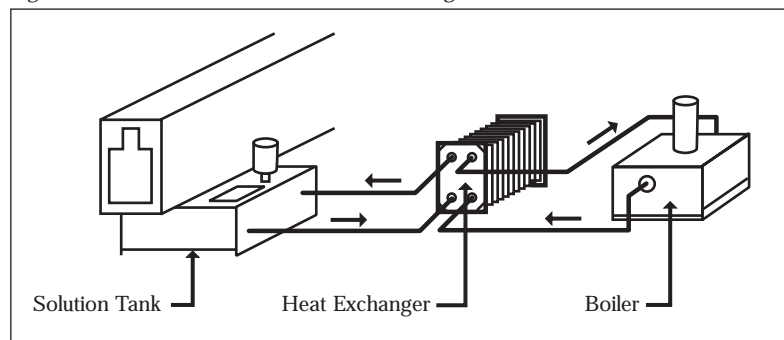
Steam Coils

Steam coils can provide efficient heating of a chemical solution. Steam from an existing plant boiler with excess capacity is cost effective. For new installations the addition of a high-pressure boiler is too expensive to be cost justified.

External Heat Exchanger

An alternative to an immersion tube or steam coil for solution heating is a plate and frame heat exchanger, mounted externally, leaving the inside of the tank free of obstructions. This device uses steam heat and is typically more expensive than a gas fired burner because of the

Figure 2-29 - Plate and Frame Heat Exchanger

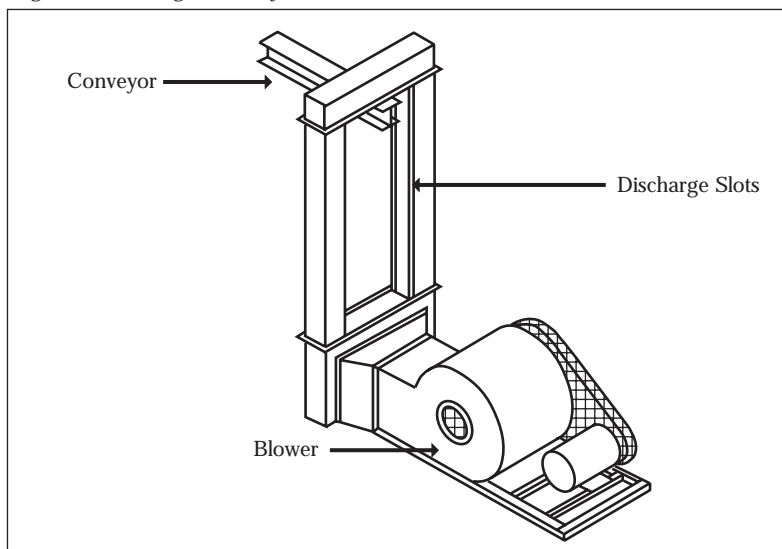


need for a small, low pressure, boiler as a heat source. It is efficient to operate and makes the solution tanks easier to clean because there is nothing inside them.

If the part has pockets that trap moisture, it may be necessary to set up a high-velocity blow-off. The blow-off will remove the heavy moisture and shear the water out, making sure that there are no phosphate residues. They also make it easier for the dry-off oven to do a complete and economical job of drying. The blow-off should have a fan discharging into ductwork on both sides of the conveyor with a filtered inlet. The discharge velocity is typically around 3,000 feet per minute (915 meters/minute). This type of blower arrangement is more efficient and less expensive than compressed air.

Some distance (at least one foot or 30 centimeters) should be left between the washer exit and the blow-off so that their respective air flows work independently.

Figure 2-30 - High Velocity Blow Off



Maintenance & Control

To ensure proper operation and consistent quality, a pretreatment washer must be carefully maintained, mechanically and chemically. A regular maintenance schedule should be established, including daily, weekly, monthly and annual tasks.

Mechanical Maintenance

- **Nozzles** - Nozzles can become worn, plugged or misaligned. Any of these conditions will reduce their effectiveness. Nozzles should be inspected daily to confirm proper spray patterns. Worn nozzles will not produce a finely atomized spray pattern and should be replaced. Plugged nozzles will not spray at all and should be removed and cleaned by removal of obvious debris and soaking in a descaling solution.
- **Risers** - The inside of the spray risers will develop scale over a period of time and restrict flow of solutions. The inside diameter should be inspected regularly and end caps removed to drain debris. The frequency for inspection and cleaning can be determined by observing the condition of the bottom nozzles; if the bottom nozzles plug frequently, the risers probably have excess scale build up. Scale build up will restrict the flow of the process solutions, reducing the volume, which will affect the pressure and performance of the sprayed solution.
The daily inspection check list shown is an example of maintenance control device.
- **Heat Exchangers** - Internal heat exchangers such as immersion tubes or steam coils will build scale on their surfaces. A scale build up of 1/32" can reduce heating efficiency by 2%. Lime scale deposits conduct only 3% of the amount of heat as an equivalent thickness and area of steel. The heat exchangers should be inspected monthly and descaled periodically.
Gas fired burners should be serviced twice a year as part of a preventive maintenance contract with a suitable service contractor. The burner inlet filters will provide a minimum of one month service in harsh conditions. They should be washed or replaced on a regular basis.

Daily preventive maintenance checklist

1. Name _____ Date _____ Time _____

2. Line Speed (fpm or meters/min.) _____

3. Washer Hour Meter (total hours) _____

4. Nozzle Inspection by Stage:

| stage | nozzle type | number changed |
|-------|-------------|----------------|
| one | _____ | _____ |
| two | _____ | _____ |
| three | _____ | _____ |
| four | _____ | _____ |
| five | _____ | _____ |

Note overall nozzle condition and measure nozzle wear: _____

Note condition of riser sections: _____

5. Filter screens:

Stage: _____ one _____ two _____ three _____ four _____ five _____

Inspected: _____

Cleaned: _____

6. Water feed system: Level OK _____ Adjustments made: _____

7. Settings:

Stage: _____ one _____ two _____ three _____ four _____ five _____

PSI: _____

Temp.: _____

Figure 2-31 – Daily Inspection Check List

Plate and frame heat exchangers are external to the tank but they still require cleaning. The cleaner stage should be flushed with a chelated acid during off hours and the phosphate should be flushed with a chelated caustic.

- **Descaling** - Scale removal using mechanical methods is difficult, time consuming and usually does not clean down to base metal. If the scale is not completely removed, it will quickly reform over the old deposit.

Chemical removal methods are less difficult and faster. Actual time to descale will vary dependent on the size of the system but usually can be completed in 4 to 8 hours.

Acid descaling solutions are effective for removing lime scale and rust but they are not very effective at removing oily soils or product residues. Usually it will be necessary to thoroughly flush out the system with a hot (140-160 °F/60-71 °C) alkaline type of material to remove the oils and grease that build up in the washer.

Once the system is degreased, rinsed and drained, the plumbing should be inspected to see if any parts are in need of repair or adjustment. Heavy deposits should be chipped away and the sludge should be removed from the bottom of the tank by flushing with a hose or shoveling.

Pretesting the descaling material on a small sample will help to determine the correct material and concentration. Usually, lime scale and rust will form carbon dioxide in an acid solution. Some types of scale, such as those formed by iron phosphates or combination cleaner/phosphates, may produce little or no reaction by exposure to acid based descalers. In cases where pretesting an acid solution does not produce satisfactory results, an alkaline solution should be tested.

In general, the descaling product will be opposite in pH to the process solution that is being removed. Descaling should typically be done once every six months to one year.

Regular service reports should be kept that document the condition of the washer, including the nozzles, operating temperature, pressures, general appearance, conveyor and washer interior condition, etc. Monitoring the washer condition with this report will give the operator the information necessary to schedule the maintenance in advance.

Any existing leaks in the washer will be enlarged when the descale solution is run through the system.

Descaling Procedure

1. While the solution is hot, remove as much free oil as possible by overflowing or use of an automatic skimmer.
2. Drain the solution from the tank.
3. Flush sludge and solids to drain.
4. Refill the tank with water.
5. Add a high caustic, high chelate alkaline descaler to reach 4-6 oz./gal.
6. Heat and circulate the solution for 1-2 hours at the highest possible heat. A low foam detergent may be added at 0.5-1.0 % by volume to help displace oils.
7. Allow the solution to remain static for 20-30 minutes.
8. Overflow to displace surface oils or use an automatic skimmer to remove oils.
9. Drain the solution from the tank. (treat the solution if necessary or drain to a holding tank.)
10. Flush sludge to drain.
11. Remove the nozzles.
12. Fill the tank 2/3 full with fresh cold water.
13. Add 10 % by volume, inhibited descaling acid (muriatic). To minimize fuming in the plant, use a low volume chemical hand pump with the discharge line immersed below the solution level in the tank.
14. Circulate and heat the solution to 120 °F (49 °C) for 1-2 hours.
15. Drain the solution from the tank (neutralize the solution prior to discharge)
16. Flush sludge from the tank bottom.
17. Inspect the nozzles, clean by soaking in a descale solution, repair or replace as necessary and re-install them in the washer.
18. Refill the tank with fresh water and heat.
19. Add 0.1-1.0 % by volume of proprietary type phosphate. Circulate washer for 5-10 minutes.

20. Drain the tank and rinse sludge from bottom.
 21. Fill the tank to operating level.
 22. Charge the tank with the appropriate processing chemical product.
- **Pump Screens** - Pump screens should be removed daily and rinsed with high pressure.
 - **Water Feed System** - Water replenishment systems should be checked daily to make sure that valves are functioning properly and that there are no leaks.
 - **Tunnel Exhaust Fans** - The washer tunnel exhaust fans are there to prevent vapor roll-out. The exhaust fan belts and blades should be checked for wear monthly. If vapor roll-out is a problem, and the fans are in good working condition, the problem could be competing plant air flows or improper exhaust volume or design. The washer manufacturer should be consulted before making any changes in the exhaust design.
 - **Controls** - Thermocouples, temperature gauges and pressure gauges should be calibrated at least once a year.
 - **Pumps** - Pumps should be greased as recommended by the manufacturer and inspected monthly for vibration, leaks, or overheating.
 - **Conveyor** - The rail and shroud inside the washer should be inspected monthly for wear.

Chemical Maintenance & Titration

Successful pretreatment depends on control of the process. The factors that affect the performance of a spray washer are the amount of exposure time, the pressure at which the solution is sprayed, the concentration of the chemical in the solution, and the temperature of the solution.

To achieve the desired level of quality that the pretreatment system was designed for, the chemistry of the washer must be carefully monitored, recorded, and maintained. Specific ranges of operation must be established and controlled. The specific variables to be controlled are process time (line speed), temperature, chemical concentration, pH, and total dissolved solids.

Titration is the test process used to check the chemical concentration of a solution. Acid base titration is based on the fact that it will take a certain amount of an acid with a known concentration to neutralize a sample of an alkaline cleaner and a certain amount of an alkaline solution to neutralize a sample of an acid solution.

A solution called an indicator is added to the solution sample prior to titrating. The indicator is usually an organic liquid such as phenolphthalein that will cause the sample to change color when it is neutralized.

- **Cleaner Stages** - Check the chemical concentration, temperature and pressure at the start of a shift, middle and end. Record all information and make adjustments as needed.
- **Rinses** - Check the total dissolved solids and conductivity three times a shift. The TDS and pH should not be allowed to rise very much over the initial raw water readings. Adjustment of the overflow volume will help to control the rinse water quality. Also, tanks should be drained and cleaned on a regular basis as necessary. The tank dump schedule and overflow rates are related. If a comparatively low volume of water is overflowed, say 1.5 GPM, the rinses may need to be dumped as frequently as once a day. If the overflow rate is 5 to 7 GPM, the rinses can be typically be dumped once a week. In cases where maintenance of the water quality is critical, softened water can be helpful. Automated rinse control based on conductivity is also possible. The key is to maintain good quality rinse water with low TDS and near neutral pH.

TDS

TDS can be measured with a dissolved solids meter, or a Conductivity/TDS pocket tester, measuring how conductive a water sample is in units of micromhos (mMho). Pure water, such as distilled water, conducts electricity very poorly and so it will give a dissolved solids or conductivity reading close to 0 micromho.

Ionic matter, such as acids, alkalis, water hardness, or salts, will make the water much more conductive and the dissolved solids reading will rise. The more dissolved matter in the solution, the more conductive it becomes.

In industrial applications, conductivity may be measured for one of three reasons;

1. To measure the purity of the raw incoming water or softened water and the suitability of that water for a given pretreatment purpose.
2. To measure the level of contamination of a rinse water solution. When conductivity rises above a certain level, the tank is usually overflowed or dumped and recharged.
3. To determine the concentration of a chemical added to the water for a certain process. The chemical may be added until a certain level of conductivity is reached.

To measure the conductivity of a sample solution, make sure that the meter is calibrated (daily) as described below:

1. Rinse the TDS meter cell cup 3 times with distilled water.
2. Rinse the TDS meter cell cup with the conductivity standardization solution and then fill it with standardization solution to at least 1/4" above the upper electrode.
3. Select the appropriate meter range for the standardization solution used.
4. Push button to read conductivity.
5. If the conductivity reading does not match the conductivity standardization solution conductivity, $\pm 1\%$, remove the bottom of the conductivity meter and adjust the calibration control as necessary.

Replace the meter battery if the conductivity reading of the meter is less than full scale when the calibration control is adjusted to its maximum setting.

After calibration, follow the procedure as listed below:

1. Rinse the cell cup three times with the solution to be measured.
2. Fill the cell cup to at least 1/4" above the upper electrode.
3. Select the anticipated conductivity range using the four position switch at the front of the meter: 10 for μMho , 100 for conductivity between 50 and 500, and 1000 for conductivity between 500 and 5000.
4. Push the button to read the meter.

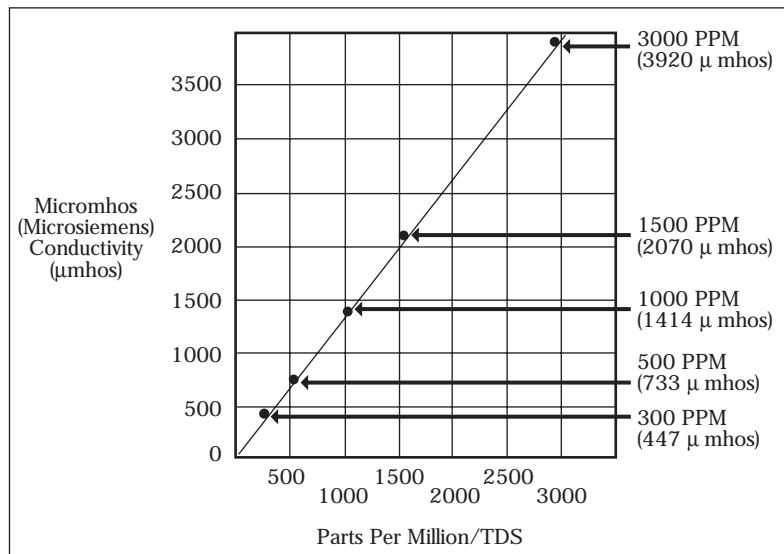
5. Multiply the reading by the range setting number (10, 100 or 1000) to get the final value in micromhos.

If the conductivity of your solution is above 5000 you must dilute the solution with distilled water before measuring and then multiply the resulting reading by the dilution factor as shown below.

$$\text{Conductivity of diluted sample} \times \text{ml of diluted sample} = \text{Conductivity of original solution}$$

The Myron L Model 532 MI TDS meter is temperature compensated for solution samples between 50 and 160 °F. If the solution to be tested is outside of this range, it should be warmed or cooled as necessary before testing.

Figure 2-32 – Conversion Chart for Conductivity/TDS



Temperature

The temperature of the solution can be determined with a thermometer in degrees Fahrenheit. The thermometer must be immersed past the groove on the lower portion of the stem in order to get accu-

rate readings. To convert degrees Fahrenheit to degrees Celsius, use the following formula:

$$\frac{(^{\circ}\text{F} - 32) \times 5}{9} = ^{\circ}\text{C}$$

pH Measurement

pH is a measurement of the relative acidity or alkalinity of a solution. 7 is considered neutral, acidic solutions are below 7, and alkaline solutions are above 7. The pH can be measured with a pH meter, a pocket type pH meter, or pH paper. Measurement of the pH provides a numerical value to relative acidity or alkalinity, an important feature in the controlling the performance of a solution.

For a solution to perform as designed, the desired pH must be known and the solution must be controlled. To illustrate the point, consider the manufacturing of jelly. In order to jell the fruit, the mixture must be slightly acidic. At a pH below 2.6, the mixture will not jell; at 2.6, a white precipitate forms and the jelly unmarketable; at 2.8, there is a separation of water droplets from the mixture; at 3.1, the mixture will produce a jelly with maximum stiffness; a pH of 3.2 will produce medium stiffness, and at a pH of 3.3 the jelly will be thin. Above a pH of 3.5, the mixture will not jell at all!

So within a few tenths of pH unit, the mixture will go from no jell to maximum stiffness and back again to no jell. This clearly illustrates the importance of tight control of the pH of a solution.

There are a broad range of acids, from sulfuric acid that can dissolve metal to boric acid which can be used as an eye wash. They all produce hydrogen ions (H⁺) in solution. The measure of acidity is the numerical value of the Hydrogen ion concentration. Expressed in chemical terms, the numerical values for Hydrogen ion concentrations are usually extremely small fractions such as 1/10,000,000. The pH scale was developed to avoid the use of such inconvenient numbers. The pH scale is defined mathematically as the negative logarithm of the Hydrogen ion concentration or the power to which 10 must be raised to equal the Hydrogen ion concentration. The name pH comes from the power of Hydrogen. This mathematical transaction provides us with a convenient scale from 0 for an acid solution of unit strength to 7 for a neutral solution of pure water.

Alkalis owe their alkalinity to the Hydroxyl ions (OH^-) which they produce in solution. Alkalinity can be measured on the same pH scale as acidity, from 7 to 14.

Simply put, any number below 7.0 is an acid and for each whole number of decline, you increase the intensity of (H^+ ion concentration) the acid by a factor of 10X. Any number above 7.0 is considered alkaline and for each whole number increase, you increase the intensity of (OH^- ion concentration) the alkaline by a factor of 10X. In a solution with the same number of H^+ ions and OH^- ions are present, the pH is 7.0.

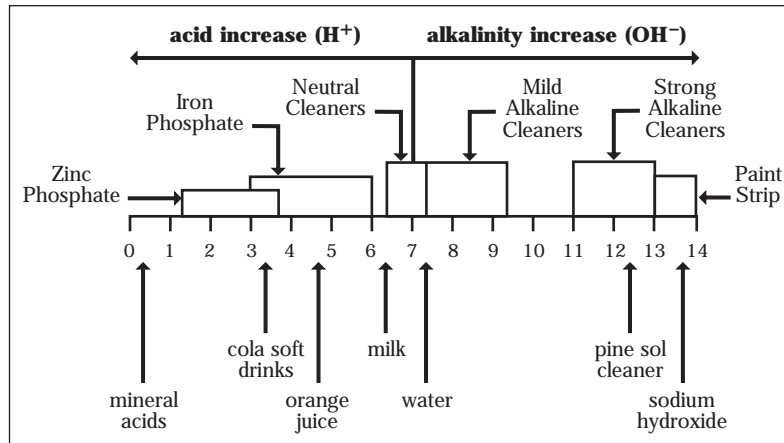


Table 7 - The pH Scale

Water from the tap may be a little on the alkaline side due to the addition of caustic soda lye to make the water "fit to drink." Proper measurement and adjustment of the water is essential to the pretreatment process. To ensure that the measurement is accurate, the meter must be properly calibrated.

II

Rinsing

Calibration by the single point method is described below.

1. Connect the pH electrode to the instrument and remove the protective cap from the electrode.
2. Rinse the pH electrode with distilled water and immerse it in pH buffer 7.00.*
3. Turn on the instrument by setting the three position rocker switch to the ON position.
4. Set the TEMPERATURE control to that of the pH buffer (use a Tel Tru GT 100R or other suitable thermometer to obtain the pH buffer temperature).
5. Adjust the STANDARDIZE control to read the buffer value corresponding to the buffer temperature. Refer to Table 1 below for these buffer values.
6. Remove the pH electrode from the pH buffer solution. Rinse the electrode with distilled water.

The pH meter is now calibrated and ready for use.

The temperature control knob on the pH meter must be set to the temperature of the solution that the pH probe is in.

The pH electrode must not be allowed to dry off. When not in use, the electrode should be soaked in pH buffer solution. The electrode should not be used in solutions above 140 °F (60 °C) and it should be protected from freezing. The electrode should be rinsed with distilled water before being transferred from the test solution to the buffer solution and it should be shaken off to reduce solution contamination whenever it is transferred from one solution to another.

If a coating has formed on the electrode tip, try to remove it by stirring briskly in a detergent solution or by spraying with a squirt bottle. If this does not work and the meter responds slowly or improperly, the glass bulb can be gently cleaned with a soft brush. If it still does not work properly, replace the bulb or meter.

pH buffer solutions should be checked periodically by comparing their pH to the pH of fresh buffer solution. Replace the solution when a pH difference of 0.1 or greater is measured.

II

Rinsing

Total alkalinity is found by taking a 100 ml sample and adding indicator "E". Titrate the sample with solution No1 until color changes from blue to green. The number of mls. required to reach the endpoint is the total alkalinity value in points (1 ml = 1pt.).

Relative alkalinity is defined as:

$$\frac{\text{Free alk. (FA)}}{\text{Total alk. (TA)}} \times \frac{10,000}{Y}$$

where Y = pre-determined factor which will vary from product to product.

For a fresh bath the relative alkalinity will always equal 100. When the relative alkalinity reaches 60 it may be time to dump and recharge the bath.

Example: F-753
Y = 50

Initial Charge -

FA = 5 pts.

TA = 10 pts.

$$\text{Relative Alkalinity} = \frac{5}{10} \times \frac{10,000}{50} = 100$$

After 3 months -

FA = 5 pts.

TA = 18 pts.

$$\text{Relative Alkalinity} = \frac{5}{18} \times \frac{10,000}{50} = 55$$

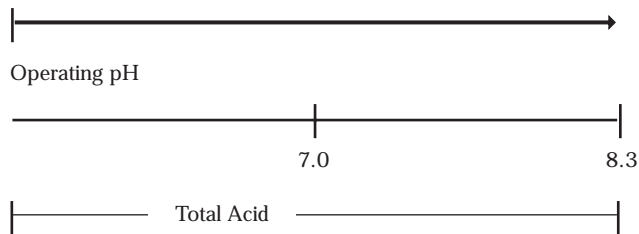
This calculation does not consider depletion of chelates, sequestrants or surfactants, only alkalinity.

- **Phosphate Stage** - A standard for the coating weight should be established and routinely monitored. The proper chemical concentration, pH (or acidity level) and temperature should be established at the start of the shift, the middle of the shift, and the end

of the shift, to maintain the balance necessary to provide the desired coating weight. Because all phosphate products and vendors have their own unique blends, be sure to follow the guidelines provided by your chemical supplier and maintain the bath at their recommended concentrations to achieve optimum results.

Total Acid – Phosphatizing Solutions

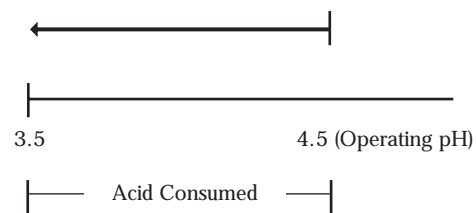
Total acid is defined as the range from the operating pH of the bath to pH = 8.3. Total acidity can be used to control the concentration of the phosphatizing chemicals in the bath.



Total acid is found by taking a 100 ml sample and adding indicator P-12. Titrate the sample with solution No2 until a light pink color appears. The number of mls. required to reach the endpoint is the total acid value in pints (1 ml = 1 pt).

Acid Consumed

Acid consumed is the range from the operating pH of the acid bath to pH =3.5.



Acid consumed is found by taking a 100 ml sample and adding indicator "E". Titrate the sample with solution No1 until the color changes from blue to green. The number of mls. required to reach the endpoint is the acid consumed value in pints (1 ml = 1 pt.). The points of acid

II

Rinsing

| Titration | Sample Size | Indicator | Titrant | Endpoint |
|------------------|-------------|-----------|--------------|---------------|
| Free Alkalinity | 100 ml | P-12 | Solution No1 | Pink to Clear |
| Total Alkalinity | 100 ml | E | Solution No1 | Blue to Green |
| Total Acid | 100 ml | P-12 | Solution No2 | Clear to Pink |
| Acid Consumed | 100 ml | E | Solution No1 | Blue to Green |

Table 9 – Titration of Alkaline Cleaners & Phosphate Baths

consumed can then be equated to pH values and used to control the pH of phosphatizing baths. As the points of acid consumed increases so does the pH. (i.e. as the pH rises so will the amount of solution No1 needed to reach the endpoint).

- **Seal Rinse** - Like tap water rinses, the variables to be controlled are pH and conductivity. The chemical vendor dictates the standard for pH level and the standard for conductivity level is the raw water plus any additional conductivity added by the seal rinse solution. These variables should be monitored along with the other rinses, three times a day.
- **DI Rinse** - The conductivity of the DI water should be monitored to be sure that it conforms to the standards earlier mentioned, 50 micromhos for recirculated DI water and 10 micromhos for fresh. Manufacturer guidelines should be followed for maintenance of the DI generation system.

Summary

The more carefully a pretreatment system is monitored and adjusted, the more consistent the results. Many finishing systems have some automatic monitoring and adjustment systems. This could be as simple as timed metering pumps or it could be as complex as complete PLC control. Automated addition of alkaline cleaning chemicals can often be achieved through feed equipment monitoring solution conductivity. While automated addition of chemicals is better from the standpoint of process control, the automatic controls must be checked to be sure that they are performing properly. There is no substitute for regular titration.

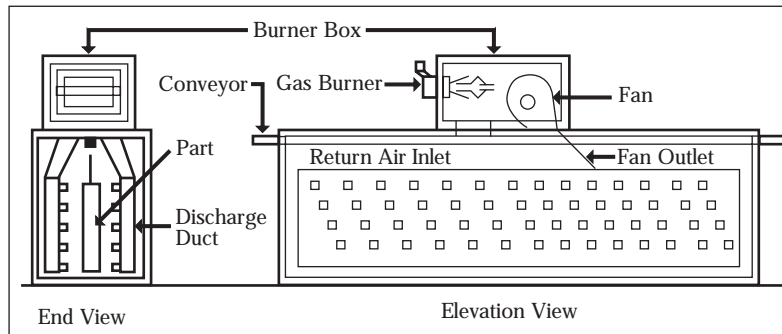


Figure 2-33 – Dry Off Oven With Recirculating Fan

Parts Drying, After the Washer

When a part has been power washed in preparation for powder coating it must be dried thoroughly before the coating is applied. The dry off oven is an enclosure with an entrance and exit that has heated air circulating through a supply duct and returning to the fan to be recirculated. The basic components are the insulated walls, supply duct, and burner box (fan and heat source).

The dry off oven can use air as well as heat to dry the part. Air blown directly onto the parts will help blow off moisture and it will accelerate the temperature rise of the substrate. When heated air is directed onto the parts, drying is faster and it can be done at lower temperatures.

The discharge velocity may be around 2,000 feet per minute (FPM) so some care must be taken to make sure that parts are not blown off of the racks. Air velocity can be adjusted by opening or closing the size of the discharge cones or slots.

Single pass ovens will have duct on each side of the product. In multiple pass ovens, duct must be run down the middle to make sure that all surfaces of the part are impinged by the discharge air from the duct.

The length of the oven is determined by the process time. The part should be in the oven for 5 to 10 minutes. The length of conveyor in the oven should be the process time multiplied by the line speed. If the oven is more than one pass, the oven size must allow clearance on the ends for the part swing through the turns.

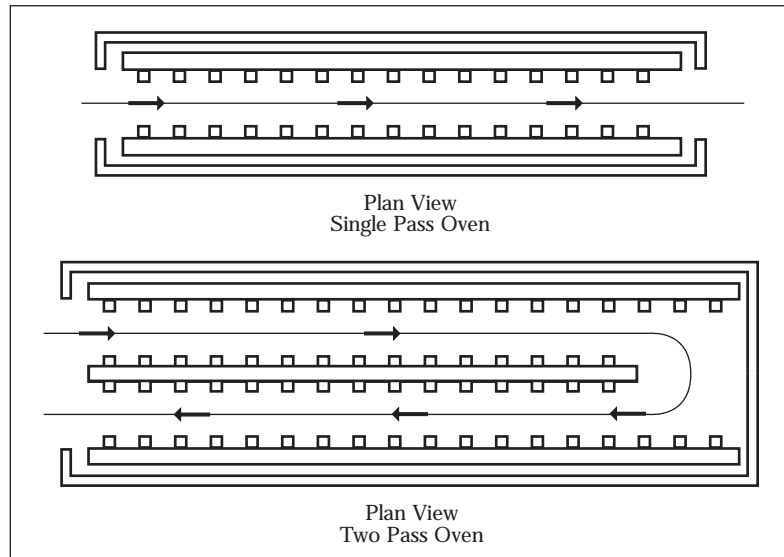


Figure 2-34 – Single & Multiple Pass Dry-Off Oven

Materials

The oven interior skin should be aluminized steel because it has superior heat resistance over galvanized or CRS. The outside oven skin can be galvanized, aluminized or painted CRS. The steel should be 20 gauge thickness. All of the oven trim should be the same metal as the skin.

Insulation

The insulation should be 4 No. density mineral wool or equivalent fiberglass and the thickness should be 1" for every 100 °F (2.5 centimeters for every 37.8 °C) or fraction of 100 °F. If an oven has a maximum rating in excess of 500 °F (260 °C), the oven panel should be 6" thick (15.24 centimeters thick). The roof and walls should be the same panel thickness but the floor may be plain concrete, aluminized skin or insulated oven panel. Elevated ovens must have an insulated floor. Floor mounted ovens should be insulated to prevent significant heat loss through the floor.

Duet Design

The duct should be made of 16-20 gauge aluminized steel. As previously stated, duct in a dry off oven should be installed on both product side walls and arranged to blow the hot air across the parts with a discharge velocity of 2,000 to 3,000 UM (610 MPM to 915 MPM). This will break up the moisture into thin sheets so that it can be easily evaporated. In a multiple pass oven the supply duet must be on both sides of the product throughout the oven. Heated air alone relies on all of the moisture reaching boiling point; it will take longer to dry a part, it will take higher temperatures, and it can leave waterspots on the part. Also, some phosphate coatings can be damaged at temperatures above 300 °F (149 °C).

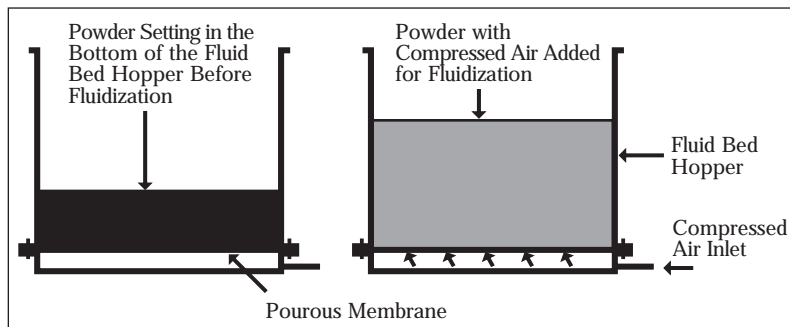
The benefits of using air impingement to help dry parts are: energy savings, no damage to phosphate coating, faster dry time, faster cool-down after drying, less floor space required.

1 Fluidized Bed Application

Early in the history of powder coatings, thermoplastic materials were applied by the fluidized bed dip process. The fluidized bed is a container that holds the powder material with an air chamber at the bottom referred to as an inlet plenum. The container and the plenum are separated by a membrane that is porous enough for air to pass through but not porous enough for solids to pass through. Compressed air is introduced into the plenum and up through the fluidizing membrane. As the compressed air passes up through the container, the powder particles are suspended in the airstream. In this suspended state, referred to as fluidization, the powder/air mixture behaves somewhat like a liquid.

Fluidized bed application is accomplished by preheating a metal part and dipping it into the fluidized bed of powder. The powder material will fuse upon contact with the hot part, creating a thick continuous film (10-20 mils) on the metal surface. In cases where the part does not have sufficient mass to completely fuse the powder, the part will be put through a short post-cure cycle, typically 3-5 minutes at 400 to 500 °F (204 to 260 °C).

Figure 3-1 – Fluidization of Powder



Electrostatic Fluidized Bed Coating

Electrostatic fluidized bed application uses the same fluidizing technique and the conventional fluidized bed dip process but with much less powder depth in the bed. An electrostatic charging media is placed inside the bed so that the powder material becomes charged as the fluidizing air lifts it up. Charged particles of powder move upward and form a cloud of charged powder above the fluid bed. When a grounded part is passed through the charged cloud the particles will be attracted to its surface. The parts are not preheated as they are for the conventional fluidized bed dip process.

2 Electrostatic Spray Application

Electrostatic spray application uses a fluidized bed as a feed hopper to hold the powder and fluidize it so that it can be pumped to the tip of a spray gun using compressed air for transport from the feed hopper to the gun tip. The spray gun is designed to impart an electrostatic charge to the powder material and direct it toward a grounded workpiece. This process makes it possible to apply much thinner coatings with a wide variety of decorative and protective features.

The electrostatic charge can be imparted with voltage, called corona charging, or by frictional contact with the inside of the gun barrel, called tribo charging.

In a corona charging system, a voltage source generates current through a voltage cable that carries it to the powder gun tip. Powder is pumped through the gun and out of the gun tip using compressed air. As the powder passes through the electrostatic field at the gun tip, it picks up a charge and is attracted to a grounded substrate. The part is then conveyed into an oven for curing of the powder. In the cure oven, the powder melts and cross-links to a hard film to complete the process.

Electrostatic spray application of powder is the most common application method. The parts to be coated are cleaned, dried, and cooled, the coating is applied and cured at the required temperature for the required time and then cooled for removal from the line.

An electrostatic spray application system includes a delivery system and a charging system. The basic pieces of equipment that make up a single application unit are:

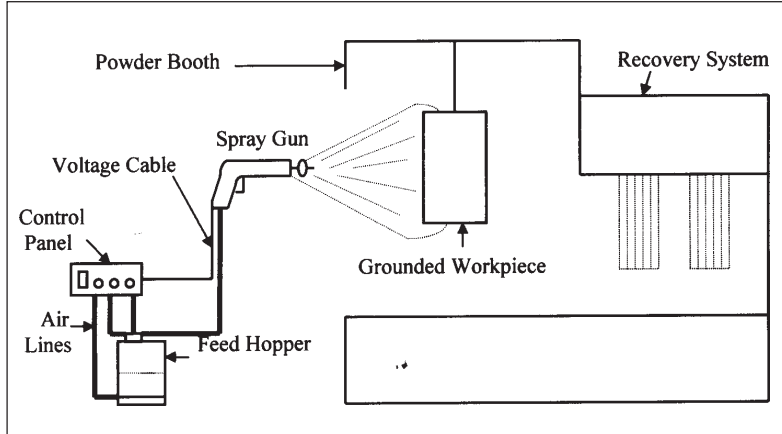
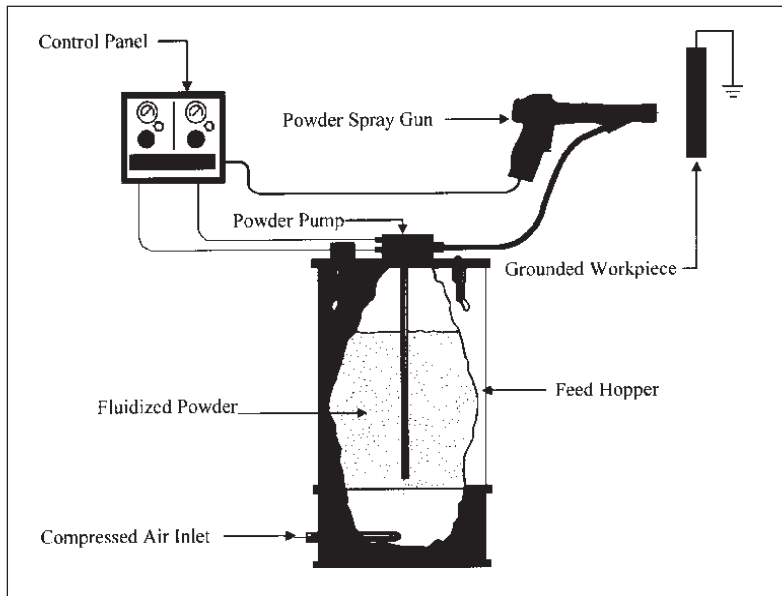


Figure 3-2 - Electrostatic Spray Application Process

Figure 3-3 - Powder Coating Spray Application Unit



- The feed hopper
- The powder spray gun
- The electrostatic power source
- The controls

These components are connected by hoses and cables and all the necessary regulators and fittings to complete the package.

The powder path through the system will abrade surfaces and may impact fuse and cause restriction to flow. The wear parts in the venturi pump and gun barrel should be checked frequently and replaced when the amount of wear causes flow problems. Hoses should be kept as short as is practical to avoid loops of hose that will restrict flow and contribute to impact fusion.

3 The Powder Delivery System

The powder delivery system uses compressed air to “fluidize” the powder, transport it to the gun tip and create a suitable spray pattern. The components of the delivery system include the pick-up tube, the venturi pump, the powder supply hose and the pneumatic controls that are used to adjust compressed air pressure.

Fluidization is the mixing of compressed air with the powder in the feed hopper. This helps to break up the powder particles, remove moisture from the powder, and provide a lightweight consistency that is easy to transport.

When powder is properly fluidized the material rises in the hopper and the surface appears to be moving like water at a low boil. If the fluid air pressure is too high, the powder cloud inside the hopper raises and makes it hard to see the surface. If the pressure is too low, small bubbles and geysers appear at irregular locations on the powder surface while the rest of the surface looks fairly still.

If the fluidization pressure is too low it will cause the powder flow rate to surge and require higher pump pressure to deliver powder from the feed hopper. If the fluidization pressure is too high, it will cause inconsistent spray patterns and pressurization of the feed hopper. Powder will migrate out of the top of the feed hopper and cover the area with potential contaminants. Powder may be separated by particle size and create inconsistencies in the finish coat.

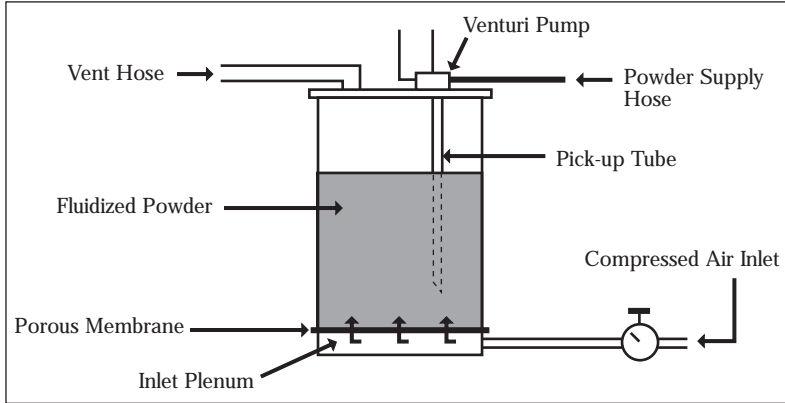
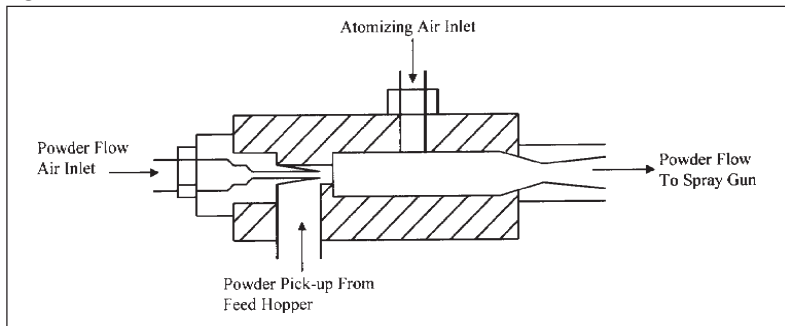


Figure 3-4 - Feed Hopper

The feed hopper has a porous tile that separates the small air plenum at the bottom from the main body of the container. The compressed air is introduced into this plenum and circulates up through the powder in the container, suspending the powder particles in a state that resembles a liquid. The powder feed hopper must be vented when the powder is fluidized to reduce pressure build-up in the hopper.

The pumping device, called a venturi, uses compressed air to lift powder from the feed hopper and deliver it through a hose to the powder gun. The compressed air is passed through the venturi pump, creating a siphoning effect. The resulting vacuum pulls the powder up and entrains it in the delivery air.

Figure 3-5 - Venturi



A second dose of compressed air is added to the delivery air to further atomize the powder and provide the transport velocity needed to carry the powder through the hose to the gun. These two airflows are balanced to provide a consistent flow of powder without surging or spitting. In addition to the fluidizing pressure and the balance of the flow and atomizing controls, the venturi pump plays a major role in providing an even flow of powder to the gun.

Powder pumps used to supply powder from the feed hopper to the spray guns should be inspected and cleaned regularly. Parts in the powder path will wear due to the abrasive nature of the powder. Worn parts will result in poor powder flow, increased impact fusion and more maintenance problems. Worn parts should be replaced to avoid these problems.

The fluidizing air breaks up the powder in the feed hopper to make it easier for the venturi pump to lift. Proper fluidization will also affect the continuous, even flow of powder to one or several guns. The volume of powder in the feed hopper will also affect consistent flow. If the hopper runs low on powder the compressed air-to-powder ratio is changed and the powder flow will have more velocity and less material.

Powder feed hoppers are available in a variety of sizes and designs depending on the system requirements and the manufacturer. Manual guns require a small volume of powder and can be fed by anything from a siphon cup up to a 250 lb. feed hopper. Manual guns are often fed straight from the box or from a 50 lb. feed hopper.

Box feed units use gravity and mechanical agitation to get the powder up the feed tube. Box feed units help reduce the time required for color change.

Some powders do not flow as well directly from the box as they will from a fluidized bed feed hopper, particularly materials with low specific gravity or materials that have been stored in humid conditions.

The chief advantage of these units is quick color change. There is no feed hopper to clean, the boxes are switched when a new color is introduced. The pick-up tube, venturi block, hose, air cap and fittings are blown off with compressed air and the color change is complete. This can be accomplished in 5 to 15 minutes.

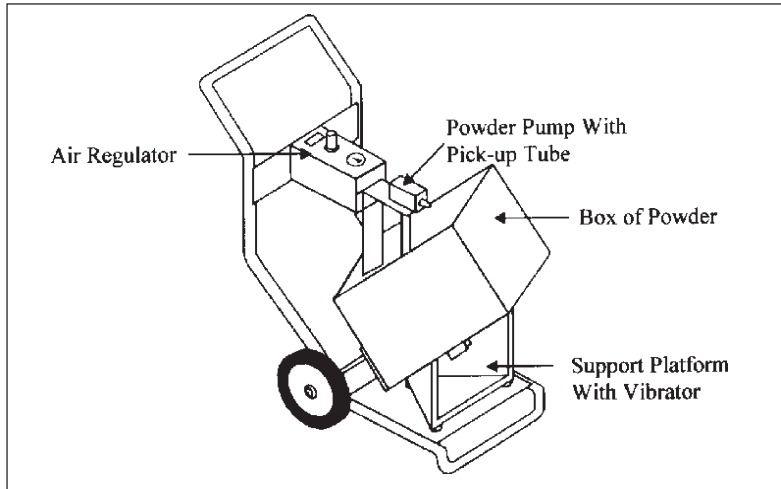


Figure 3-6 – Box Feed Unit

Box feed units can be a real asset for coating lines that run a lot of short runs and make frequent color changes. When box feed systems are used it is still useful to have a feed hopper that can be used to handle the occasional powder material that does not pick up well from the box.

Sets of automatic guns require a larger volume of powder and therefore a larger feed hopper. A typical range of size for automatic installations is 150 to 250 lbs. These large feed hoppers are not really designed to be color changed. Large feed hoppers are typically dedicated to a single color.

Some systems that use automatic application equipment may not always wish to recover all of their colors. There are situations where short runs of various colors do not generate enough overspray to justify the equipment or labor needed to reclaim the overspray for reuse.

Large feed hoppers are very difficult to color change and dedicated feed hoppers are not always cost justified. In systems that run automatic equipment and do not reclaim the overspray for reuse it is a

smart idea to have a pair of smaller hoppers, say 80 lbs. each, that are more easily color changed.

Powder Sieve

Sieving devices are frequently used in conjunction with automatic system feed hoppers to screen out dirt, clumps of powder or other contaminants, prior to spraying. There are vibratory and rotary sieves used for this purpose.

Rotary sieves are often mounted directly to the top of the feed hopper and the powder is passed through it from the recovery system. Powder is fed into the rotary sieve from an accumulator. A motor driven impeller feeds the powder into a cylinder. Air currents cause the powder to pass through a screen in the cylinder. Foreign material passes through the cylinder to the end and into a scrap receptacle.

Reclaimed powder should always be sieved to remove dirt from the material. Automatic systems that are run without a sieve will collect fuzz and other dirt that can impede the flow of powder, cause surface defects and collect around the electrode, interfering with charging efficiency.

Since manual systems do not use a sieve to help break up the powder and remove dirt, it is a wise idea to introduce the powder to the feed hopper through a screen. A piece of stainless steel hardware screen works well for this purpose. A screen mounted on top of the feed hopper can remove large chunks of powder that occasionally come in the box and it will help to break up clumps that may interfere with the flow of the powder.

Compressed Air Supply

The air used to fluidize a powder feed hopper and provide flow to the guns must be clean and dry. Oil, moisture or rust scale in the compressed air supply can contaminate the powder and block airflow through the porous membrane or regulators.

A rotary or a reciprocating compressor is satisfactory for powder coating systems. The reciprocating compressor is the most common but the rotary unit is typically less expensive, quieter and easier to install. The separators in the rotary unit capture a lubricant that is used for

sealing and cooling and they must be cleaned regularly to avoid carry-over into the air system.

Powder coating requires the compressed air supply to be at **+38 °F dew point or lower with less than 0.1 PPM of oil and no particulate greater than 0.3 microns in size**. A typical powder coating compressed air supply system will include the following items, listed in order;

- the compressor
- an aftercooler
- a separator
- a receiver
- a moisture eliminating pre-filter
- an air dryer
- a final filter

Moisture or contamination in the air supply will create surface defects, make it harder to get the powder to flow, and damage the spray equipment.

The Charging System

Powder without a charge is like dust, it will float and land in an inconsistent pattern. In order to apply the powder over a specific surface in a uniform pattern, a charge is supplied to the material. The powder particles are passed through a charging field by the delivery system to impart an electrostatic charge. The electrostatically charged powder material is attracted to a grounded substrate.

The function of the powder spray gun is to shape and direct the flow of the powder, help to control the spray pattern shape and size, and impart an electrostatic charge to the powder. There are a wide variety of spray guns available, manual and automatic, with different methods of supplying a charge. The two common types of spray guns used are corona charging guns and tribo charging guns.

Corona Charging

Corona charging systems are the most widely used type of electrostatic spray equipment. Corona equipment uses voltage to supply a charge to the powder particles.

Powder is pumped from the feed hopper through a hose to the tip of the spray gun by the delivery system. A charging electrode at the gun tip is connected to a high voltage generator. The generator can be located inside the control panel and connected to the electrode by a high voltage cable or it can be located inside the gun barrel. High voltage multipliers that are inside the gun barrel are connected to the control panel by a low voltage cable.

When a corona-charging gun is triggered it will create a sharply non-uniform electric field between the gun tip and a nearby grounded object. Field lines will develop between the sharp tip of the gun electrode and the surface of a grounded part.

Free electrons or ions are always present in the air. If these free ions pass through the strong electric field at the gun tip, they will begin to move along the field lines and get accelerated by the field force. As electrons accelerate along the field lines they will collide with air molecules.

When the combination of applied voltage and electrode geometry creates an electric field in excess of the breakdown strength of air, a corona discharge is generated. The impact of the free ions on the air molecule will be strong enough to split it, forming two secondary negative ions and one positive ion. The secondary electrons will get accelerated in the electric field and repeat the process of splitting air molecules to form more free ions. The resulting negative ions will accelerate along the field lines to the part while the left over positive ions will accelerate along the field lines in the opposite direction, toward the gun electrode. The space between the spray gun and the grounded part becomes filled with millions of free electrons and positive ions.

The grounded, conductive parts provide a receiving electrode to form an electrostatic field between the gun and the part. As powder particles pass through this corona, they become charged, usually with negative ions, and follow the electric field and the air currents to the earth grounded workpiece. As air brings the particles within a few centimeters of the part, Coulombic attraction pulls the particles toward the part surface and causes them to adhere there until some other force interferes or they are cured by the introduction of heat or radiant energy.

The ability to take a charge is most strongly affected by the field strength, the powder particle size and shape, and the time that the

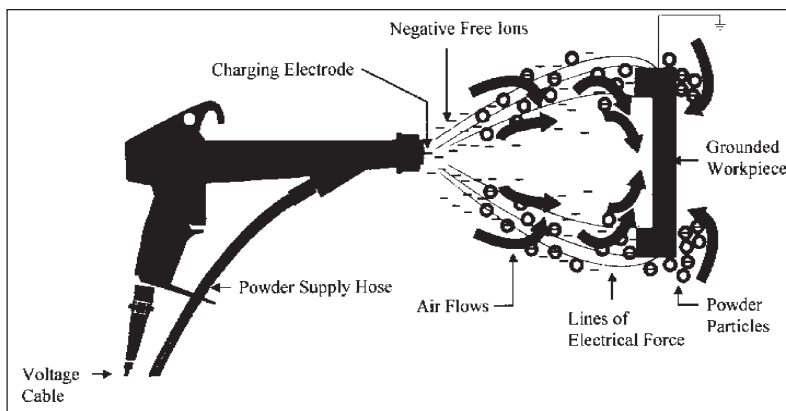
particle spends in the charge area. The electric force will push the particle towards the grounded substrate. Air resistance, aerodynamic force, and gravity can pull the particle away from the part. The air-stream will deliver the particle to the part but if the particle is not charged or the field strength is not sufficient the particle will be carried away from the part by these other forces.

The polarity of the charging electrode can be either positive or negative. A negative charge is generally preferred because ions can be generated in greater number with less arcing.

The factors that affect corona charging are the gun-to-target distance, the velocity of the powder, the electrode and nozzle configuration and the presence of a well grounded part to act as a receiving electrode.

Electrostatic field lines develop between the gun electrode and the grounded part and connect to the part at right angles. These field lines are more concentrated at sharp points, sometimes resulting in higher deposition on edges of the part surface. A great number of free ions are present in the space between the gun and the part. Powder particles exit the gun and capture some of the ions in the area and become charged. Many of the ions remain free. The charged powder and the remaining free ions travel along the field lines towards the grounded part. This combination of charged powder parti-

Figure 3-7 – Corona Charging Powder Gun



cles and free ions has a cumulative potential that is often referred to as “space charge.” In a corona charging system, the electric field near the part surface is comprised of the fields created by the discharge electrode of the gun and the space charge. This two fields combine to provide efficient deposition of the powder material on the grounded part.

Faraday Cage Effect

Large flat surfaces provide a perfect target for the strong electric fields created by the corona charging system. The same forces that provide efficient deposition on larger flat surfaces can create some problems on parts with more complex geometries. This creates the phenomenon known as Faraday cage effect, named for Mr. Michael Faraday who conducted many experiments of static electricity. Faraday areas are inside corners and recesses that are resistant to powder deposition.

The electrostatic lines of force will tend to concentrate on the edges of the recess because there is less resistance to electrical forces than there is inside the recess. Powder will build rapidly on the edges, following the field lines, and much less powder will drift into the recesses.

As the powder preferentially builds on the sharp edges and prominent ground points it produces an image field on the part surface and begins to become self-limiting. In addition, the conductive surface of the part shields the inside corners from the electrostatic field produced by the gun. Also, the air carrying the powder tends to swirl inside the Faraday cage area, sweeping powder away. This combination of forces makes coating of recesses one of the more difficult challenges faced by the powder coater. The only force that contributes to deposition inside the recess is the field created by the space charge of the powder particles that are delivered by the air stream inside the recess.

Since the field lines from the discharge electrode will follow the path of least resistance to the leading edges of the recess, there is rapid development of field strength in those areas. This will generate some positive ions, which will reduce the charge strength of those particles that pass the edges and continue into the recess. When this happens the cumulative space charge of particles that pass the leading edges of the Faraday area is not sufficient to cause powder to be attracted to

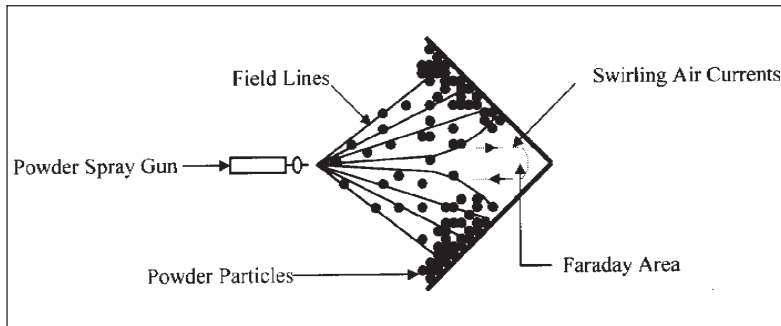


Figure 3-8 – Faraday Cage Effect

the metal surface. This problem is directly related to the build up of free ions at the part surface.

The trouble with inside corner penetration is much more difficult in situations where the part is poorly grounded. Many coaters do not check the ground of the part on regular basis. Ground checks should be a routine part of the daily operation of powder system.

Most corona guns provide a negative charge. The powder particle enters the gun in a neutral condition and the free ions present in the corona field add additional electrons to the powder particle. Following the nature of matter, the particles are attracted to a ground source to discharge these electrons and regain neutrality. This is what causes the powder to cling to the workpiece.

The phases in the charging sequence of a negative charging corona gun are:

- high voltage is supplied to the electrode at the gun tip
- the concentrated voltage creates an electric field
- the electric field causes ionization of the air
- the ionized air generates a corona
- the corona emits electrons
- the electrons collect on oxygen molecules to form negative ions
- these ions follow field lines established by the voltage discharge
- the powder particles distort the field around them

- the distorted field lines direct the ions to the powder particles
- as the ions collide with the powder particles the electrons are transferred, providing a negative charge to the particles.

The success of the process is dependent on many variables. Charging is most strongly affected by field strength, particle size and shape, and the time that the particle spends in the charging area. An individual powder particle has very little mass. Some particles do not charge and some are influenced by airflow and other forces. But many of the particles will charge and seek ground. For good transfer efficiency, it is essential that the target part be the most prominent ground in the discharge area.

Most powder materials are strong dielectrics. Once they are charged, the charge will not bleed off quickly. As the powder particles reach the grounded surface, they induce a charge of equal value and opposite polarity on the inside of the metal. Electrons inside the metal will vacate the area, leaving a positive charge that attracts the negatively charged powder material. This charge in the metal is commonly called “mirror charge.” The opposite charges attract each other and hold the powder particle to the metal surface. They also generate another electric field between them. A larger powder particle with higher charge will contribute to a stronger electric field between itself and the surface part surface.

Larger powder particles typically build more charge than smaller particles. As they build up on the surface they may create resistance to the deposition of smaller particles with a weaker charge. This is one of the factors that can contribute to “orange peel,” the slightly textured look of a thick powder film after curing. This will be particularly apparent if the powder does not stay in the flow cycle long enough to help the film level out.

Back Ionization

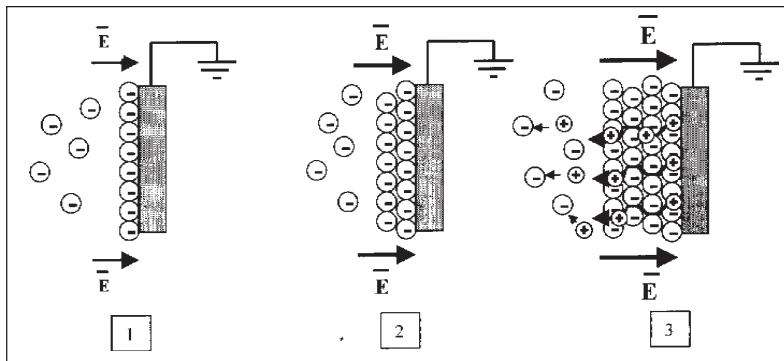
As powder is applied to the surface of the metal, the strength of the electric field inside the layer of material will increase. As the number of charged particles increases on the surface, the negative charge in the powder film and the positive “mirror charge ” inside the metal increase, causing an increase in the strength of the electric field inside the layer of powder coating. As the application of powder continues, the strength of the electric field may build to a point where it will begin

to ionize the air trapped between the powder particles. This will cause an effect very similar to the corona field at the gun tip. Stray electrons will accelerate in the electric field and split air molecules, generating a large number of negative electrons and positive ions. The negative electrons will tend to attract to the positive ground, while the positive ions will try to make their way out of the powder film, towards the negative electrode at the gun tip.

This intense build up of an electric field at the surface of the part creates small sparks that shoot up through the powder layer. This phenomenon is commonly referred to as back ionization. This repelling force forms micro craters on the powder surface, commonly referred to as "stars." Also, as the positive ions travel along the force lines toward the gun electrode, they collide with negatively charged powder particles, neutralizing them, contributing to the self limiting characteristics of electrostatic application and reducing transfer efficiency. This process is illustrated below.

In picture number 1 the powder begins to deposit on the grounded surface. In picture number 2 the material thickness on the surface increases and so does the cumulative charge of the powder layer and the resulting mirror charge. This increase in these two charges will increase the strength of the electric field in between the powder layer and the metal surface.

Figure 3-9 - Back ionization



As the powder continues to build on the surface the strength of the electric field inside the powder-coating layer will eventually become high enough to ionize air trapped between powder particles. When the air begins to ionize it will create the same atmosphere as the corona discharge from the gun tip, accelerating stray electrons in the electric field, splitting air molecules, and creating additional negative and positive ions. Because opposites attract, the negative ions will rush toward the relatively positive charge on the part surface and the positive ions will begin to move out of the powder layer toward the gun's negative electrode as shown in picture number 3. This intensive flow of ions within the powder layer will cause streamers to develop in the freshly applied powder coating. These streamers are like tiny bolts of lightning shooting up through the coating. The streamers carry positive ions out through the coating layer, causing disruption of the surface and neutralizing negatively charged particles. This intense disruption in the coating surface is called Back Ionization.

The forces associated with back ionization can drastically reduce transfer efficiency, contribute to orange peel, and create "starring," small craters in the coating surface.

A large number of free ions are present in the air between the gun and the part. Before the powder begins to develop on the surface there is low resistance to electrical conductivity and the path to ground is unobstructed. As the powder builds and insulates the surface it will create resistance to ground. Free ions travel along the field lines and as they arrive at the surface they can contribute to rapid back ionization and difficulty with application into Faraday cage areas.

Electrostatic Wrap

As powder approaches the grounded part along the field lines, a portion of the material will be attracted to the back surface from a force that is commonly referred to as electrostatic wrap.

The "wrap" in a particular situation will depend on the charging efficiency and the airflow characteristics of the booth and the delivery equipment. Booth airflows must not be so aggressive that they interfere with electrostatic deposition and gun flows must not have enough velocity to blow powder past the part.

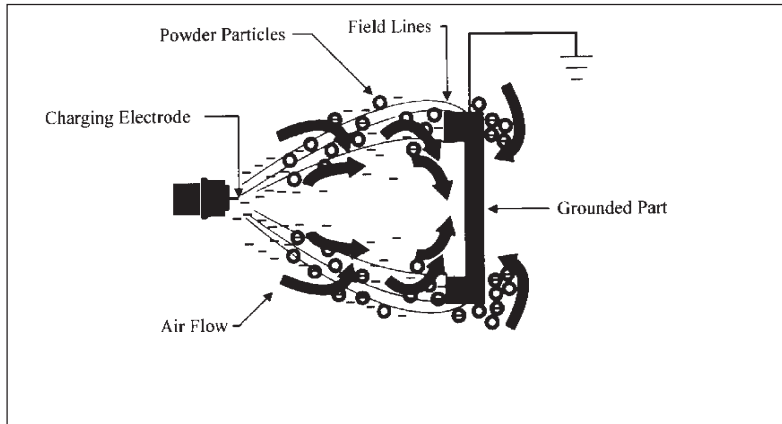


Figure 3-10 – Electrostatic Wrap

Voltage

The high voltage can be supplied from an external source through a high voltage cable or increased inside the gun barrel by a multiplier.

External Charging Gun

With an external charging gun, an electrostatic charge of 30-100 kV is generated by a high voltage stack located in the control panel and delivered through a high voltage cable to the electrode at the gun tip. The electrostatic charge on the electrode is usually negative polarity and can be regulated in the level of kilo voltage by the electrostatic power source.

The level of electrostatic charge used depends on the shape of part and the powder being sprayed. Generally, surfaces that do not have much Faraday area (recesses and inside corners) should be coated at the highest possible voltage with the lowest possible airflow. Faraday areas will usually coat more successfully with lower voltage. The lower voltage reduces the tendency for repelling of powder particles in the inside corners.

All powders do not behave the same when subjected to electrostatic charge. For example, a typical polyester or polyester/epoxy hybrid may charge better than epoxy. Therefore, it may be necessary to

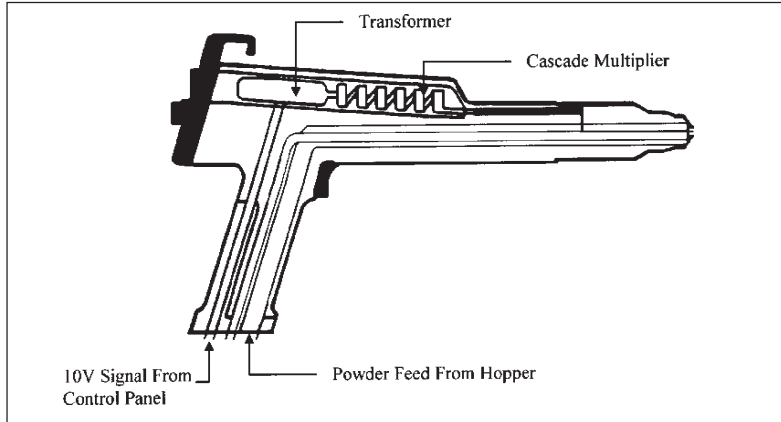


Figure 3-11 – Integral Power Supply Corona Gun

reduce voltage or flow rates to control the film build or reduce back ionization with some powders. Particle size and distribution of the powder particle size range also affect thickness of the powder film.

Position of the spray gun, length of spray time, level of electrostatic charge and velocity and volume of the powder can control the film thickness.

Integral Power Source

With this type of gun the voltage is stepped up inside the gun barrel. A low volt signal is supplied to the gun from a DC power supply in the control panel through a low voltage cable to an oscillator. The signal from the oscillator is increased by a high voltage transformer to approximately 10 kV. This signal is stepped up to a range of 80 to 100 kV by the cascade multiplier in the barrel of the gun up. A blocking resistor in the gun barrel prevents discharge of stored energy in a single surge to provide safe operation and avoid surface defects.

Counter Electrode

A corona spray gun develops lines of force that extend from the charging electrode to the target part. The lines of force will influence the path of the powder and the resulting deposition. The lines of force tend to “connect” to the part at points that are easiest for voltage to

travel. On parts with irregular geometry, the lines of force will concentrate on the most prominent surfaces and avoid tight recesses and inside corners, the Faraday cage effect.

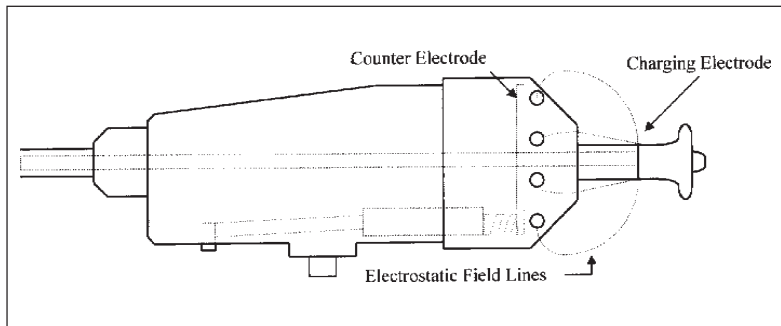
Corona guns can be adjusted to overcome Faraday cage areas but it is one of the most frequent issues that challenges powder coaters.

One option in application technology that helps to reduce the impact of Faraday areas is a counter-electrode. This type of spray gun has an ionizing electrode and a counter-electrode. Most of the ions produced by the ionizing electrode are pulled to the counter-electrode, directing the lines of force away from the part. With no concentrated lines of force connecting to the part, the ability to penetrate into inside corners is improved.

The counter-electrode gun can produce consistent films and good penetration without excess thickness on complex shapes.

The voltage for this gun is set at 35 to 40 kV and the useful current is 80 μ A. Flow rates are generally low to ensure good charging, given the relatively short exposure to the corona field. As a result, the counter-electrode gun is best suited to lower volume applications where there is a need for penetration of Faraday areas while controlling thickness on flatter surfaces. Large amount of surface area would require more guns than standard corona charging devices designed for higher output.

Figure 3-12 – The Counter-Electrode Spray Gun



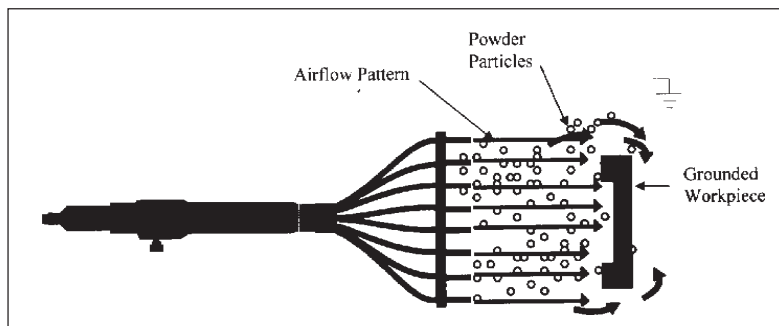
It is essential that the charging electrode be kept clean with all corona guns to be sure that the ion field is effectively charging the powder. With the counter-electrode gun it is important to keep both electrodes clean.

Tribo Charging

Another device that can help to deal with Faraday cage effect is the tribo-charging gun. In a tribo-charging gun, the powder particles are charged by frictional contact with the material inside the gun body. A powder and air mixture enters the gun and passes through a tubular section that is made of a material that is known to be a good acceptor of electrons, such as Teflon. As the powder particles collide with the walls of the tube, they pick up a positive charge by giving up electrons to the tube, causing the tube to become negatively charged. The negative charge is then passed from the gun barrel to ground through a cable.

The powder material must be a formula that is a good electron donor, such as nylon or epoxy. Not all powder materials can be used effectively in a tribo-charging gun. In addition to the powder chemistry, tribo guns are more sensitive to particle size than corona guns. Generally, larger particles will be more effective in a tribo gun. Powder material suppliers can work with the applicator to make sure that the material is suitable for tribo application.

Figure 3-13 – Tribo Charging Spray Gun



A tribo system can assist in the penetration of Faraday areas because the positive charge is generated by friction and does not have the field lines that are present with a corona charge. With no discharge of high voltage, like that used with the corona gun, there is no build up of free ions on the surface to interfere with coating deposition.

Because the tribo gun does not create a highly ionized surface on the part it is very useful for blank coating operations. Corona charging in operations using a belt to convey blank sheets of steel will create a highly ionized electrical field in the belt and cause disruption of the application process from back ionization.

Another advantage of the tribo gun is the ability to recoat parts without back ionization. Because the surface does not receive a large number of free ions, it is not as hard to get the second coat to adhere. Again, there is no back ionization, so the coating can cover without the interfering forces of a voltage charging system.

The tribo charging method can help to achieve uniform coverage and a smooth film over a surface with angles. In applications where very deep penetration is required the tribo gun can provide good coverage without building excessive film on the outer edges.

One limiting factor is the powder material. Materials must be compatible with frictional charging. Some stock materials may not work in a tribo charging spray gun. A high content of fines in the powder material will cause application problems. The compressed air supply must be reduced to around 200 °F dew point.

Powder Bells & Discs

The powder bell is fashioned with some of the same principals as rotary atomizers made for the application of liquid coatings.

The powder bell is mounted in a horizontal position on a stationary or reciprocating gun mount. A turbine rotates a bell shaped disc at the gun tip. Powder is delivered to the bell by compressed air. The centrifugal force of the rotating bell ejects the powder in an even pattern from small holes or slots around the edge of the disc. The charging electrode is disk or needle shaped and located at the gun tip. The corona field and charging method is the same as a standard air spray gun. The pattern and velocity can be controlled by the rotational speed of the bell and a "shaping" air supply.

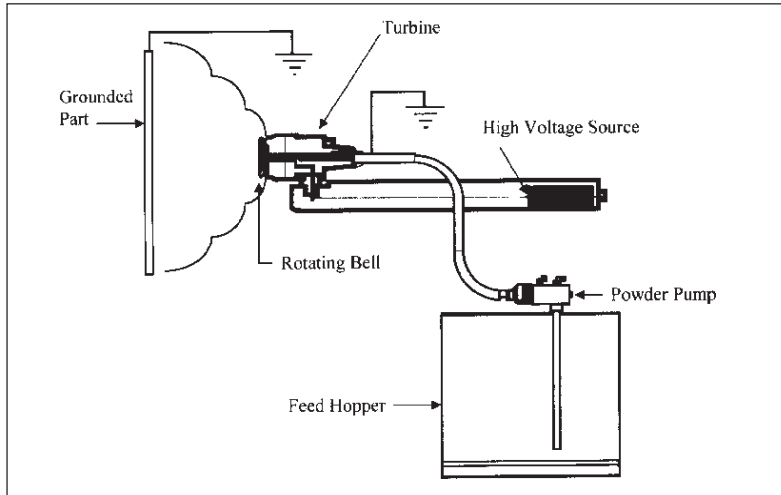


Figure 3-14 – Powder Bell

The bell can deliver a large volume of powder over a large surface area with a high level of charging efficiency. Large surfaces without significant Faraday areas can be coated with excellent film thickness control and high first pass transfer efficiency (FPTE).

The pattern of powder delivered from the bell is broader than a typical spray gun and more concentrated around the edges than in the center. In systems where gun triggering is used the bell may not be as efficient as a spray gun because of this large spray pattern. The bell needs to be triggered before the part arrives and remain triggered until the part passes. Since the bell pattern may be as much as 18" wide a lot of overspray is generated during the lead into the spray zone and the lag out of the spray zone.

The powder disc is mounted on a long stroke, vertical reciprocator, inside an "Omega" shaped booth. Like the bell, it is capable of providing very high transfer efficiency. The dwell time in the spray zone is longer than a conventional booth and the wrap and penetration are very good. Unlike the bell, the disc does not rotate. The powder is tribo-charged and delivered to a large disc, which is located at the bottom of the gun body. The disc deflects the powder out in a circular pattern towards the parts as they pass through the Omega-loop booth.

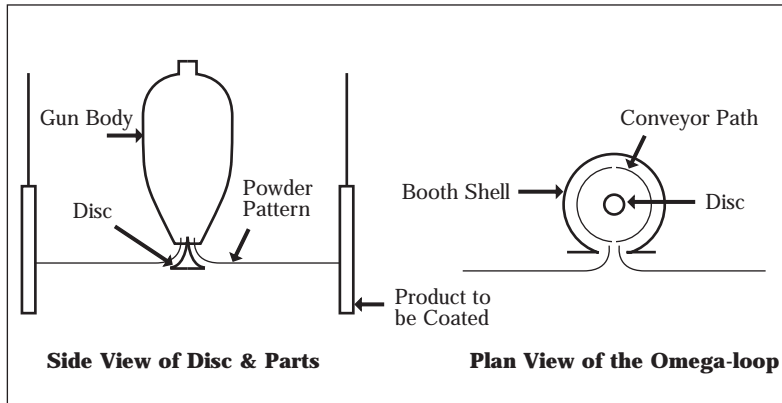


Figure 3-15 – Powder Disc

The disc is capable of powder flow rates up to 180 lbs./hr, which provides a theoretical coverage of over 30,000 ft²/hr. It can be an excellent retrofit for existing Omega-loop liquid disc system.

At least one manufacturer offers a powder bell that does not rotate. This bell uses a shaping disk that produces a 360° conical pattern extending up to 35 inches in diameter. A special edge charging material is sandwiched within the disk to provide an expanded area of charge.

With a large powder pattern and charging surface, this device provides good transfer efficiency over a broad surface. Since the conical bell shape is non-rotating, it can be retrofitted to an existing powder spray gun.

4 Determining the Application Package

Choosing the right application package will depend on the nature of the task. The corona gun, tribo gun, the bell, and the disc are all tools that can meet certain requirements. No single tool is perfect for every powder application.

A corona-charging gun offers more methods of adjustment for differences in part size and geometry. Air flow patterns, powder volume, velocity, and voltage level can be adjusted to accommodate different

parts and powders. This gives the operator a lot of flexibility in controlling film thickness, dealing with Faraday cage and other process variables that are common in production facilities. The use of discharge voltage creates field lines and a highly ionized electrical field that can cause a variety of application challenges.

Generally, a tribo system will work best in situations where there is not a lot of variety of parts and powders. With a tribo gun, the powder volume can be adjusted and the gun to target distance can be adjusted. The best application for tribo guns is one where there is little or no need for adjustment. One powder and a fairly consistent mix of parts can be run very effectively with a tribo gun. Used with the correct powder material, the tribo gun can be very effective. Testing should be conducted to be sure that the powder material is compatible with this positive charging device.

Most powder operations in North America use the corona-charging gun to take advantage of the flexibility of voltage control and ability to spray any thermoset powder effectively. In Europe more tribo spray guns are used to take advantage of the penetration characteristics.

The powder bell is well suited to high volume lines with a lot of surface. It would be great for shelving for example but not very good for picture frames where there is a lot of empty area and very little surface. An air spray gun will likely provide better penetration into Faraday cage areas than a bell.

The disc is a specialized piece of equipment for product that is densely hung and long in the vertical dimension with very little thickness. Aluminum extrusions, large batches of small parts and wire goods are good examples.

Any purchase of powder application equipment should involve testing, particularly when the equipment will be automatic. Testing can be used to compare manufacturers and to try out and compare different tools. Processes can be tested, proven, documented, and used to assist with start-up when the installation is ready for production.

Application System Automation

Many powder systems are equipped with manual application equipment only. With an average sized product opening, say 30" wide by

54" high, two manual operators should be able to keep up at a 6 feet per minute (1.8 meters/minute) conveyor line speed. As the volume of product to be coated increases, either in the size of the work package, line speed or both, automatic application equipment becomes necessary.

In addition to the ability to handle more volume, automation can provide some advantages in reduced labor and improved efficiency. Automatic guns can cover 80 to 100% of the parts. Manual operators may be needed to cover the remaining bare areas and they can also serve as inspectors. In some cases, the parts are fully covered with automatic guns and there is no need for manual reinforcement.

Many automated systems use fixed position gun mounts but in many cases, gun movers and part recognition systems can be used to improve efficiency and reduce waste. In most cases, it will require more automatic guns to coat a given vertical work area with fixed guns than it will if the guns are moved up and down. Also, gun movement will help to prevent the development of excess ionization on the part surface.

The equipment supplier will help to determine the precise package that is best in each situation. The need for automation will depend on the volume of product to be coated, the expectations and goals of the applicator and budget for the project.

Gun Movers

Machines that provide a straight up and down motion are called oscillators or reciprocators. An oscillator is typically a crank arm and fly-wheel design that can provide a vertical stroke of 6 to 24" (15 to 61 centimeters). A reciprocator is a more complex device with a reversing or reciprocating drive and adjustment from 16 to 144" (41 to 366 centimeters). Stroke speed is also adjustable. With both devices, guns can be mounted in a straight vertical line, a horizontal line or a combination of both, depending on the needs of the operation.

Radial Oscillator

A radial oscillator uses two vertical bars, one that moves up and down with the drive and one that is stationary. The gun body is mounted on both bars so that as the one bar moves it produces an arcing motion.

III

Determining the Application Package

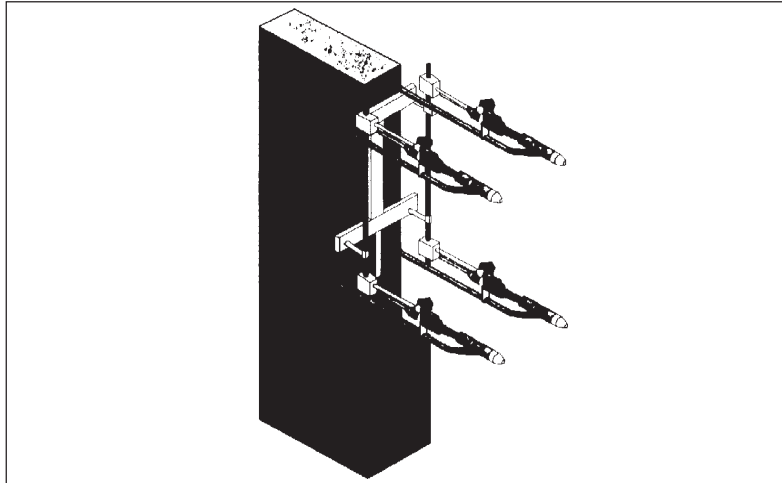
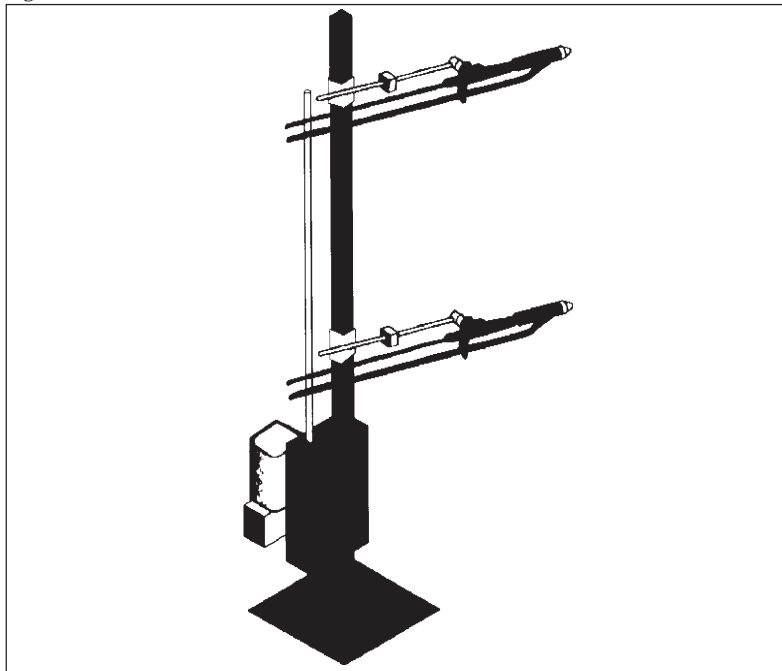


Figure 3-16 - Reciprocator

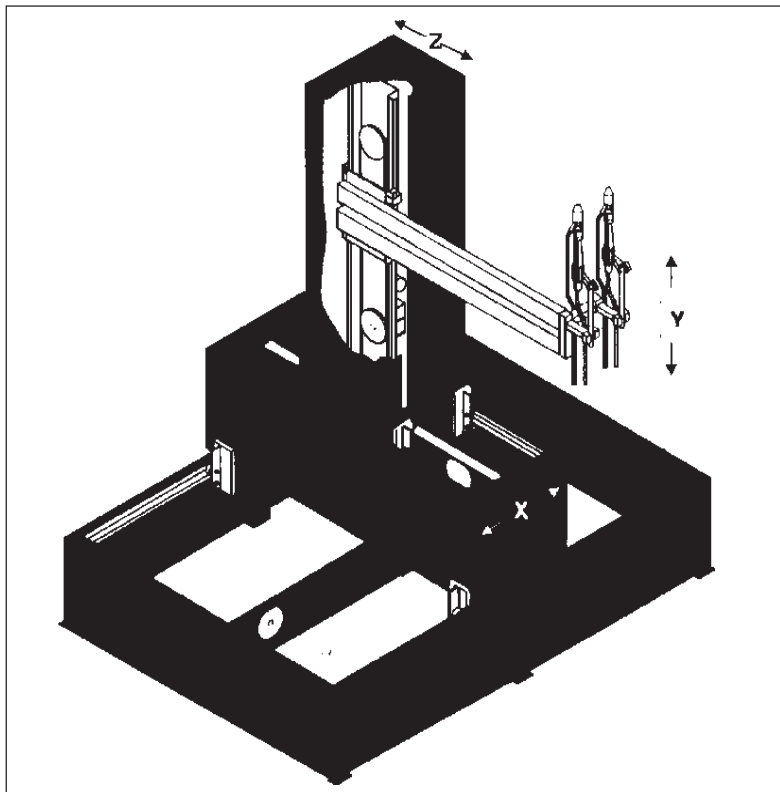
Figure 3-17 - Radial Oscillator



The arcing motion has its advantages and disadvantages. At the top of the stroke, the gun is aimed slightly up where it can help to coat the bottom of the part; and at the bottom of the stroke, the gun is aimed down, helping to cover the top of the part. The gun to target distance changes as the unit moves and this can cause some inconsistencies in film build.

Radial gun movers are relatively inexpensive and they can be very effective. Like the reciprocator, the radial oscillator does increase the vertical area that one gun can cover.

Figure 3-18 – Multi-Axis Gun Mover



Multi-Axis Machines

A multi-axis machine, commonly called an XYZ machine, moves the parts in more than one direction. In addition to the vertical movement of a reciprocator, they also move in direction of conveyor travel, and in and out. This provides a lot of flexibility to coat complex shapes and maximize system efficiency.

Robots

The advantages of using a robot are replacement of manual labor and more consistent, repeatable application. It is also capable of making adjustments in voltage and flow rates in the middle of the spray operation through the controlling PLC. There are hydraulic and electric robots used for coating. The hydraulic robot is less expensive but the electric is preferred because it is smoother, more accurate, faster, and requires less maintenance.

Gun Triggering

In addition to the gun movers, it has become increasingly common to use automatic gun triggering. A photo-eye or bank of photo-eyes is mounted on a stand on one side of the conveyor, in line with reflectors on the other side of the conveyor. As parts pass through the photo-eyes, they break the beam of light to the reflector and send a signal to a microprocessor to provide part size information. An encoder is used to sense conveyor movement and provides information on part position for timing of gun triggering. The output from the microprocessor controls what guns come on and when.

Gun triggering is used to identify part presence and line gaps. It is also used to determine the size of the part and react to the length, triggering only the number of guns that are required. It can also be used to reduce or increase the electrostatic wrap, helping to reduce fatty edges on simple flat product and enhance edge coverage on the side of the parts.

Liquid coaters have done this for many years to reduce overspray. For them, the reduced overspray means less paint waste and lower emission levels. For the powder coater, gun triggering can provide significant savings in several areas.

- Better Overall Powder Material Utilization - A percentage of material is lost when it is sprayed, to the racks, from handling, in the clean up process, etc. It can be as small a percentage as 5% or, in the case of spray-to-waste systems, 100%. It pays to reduce the total amount sprayed.
- Powder materials are delivered in a particular range of grind size, measured in microns. Analysis shows that after reclaiming powder, the range of grind size shifts and the blend has a higher percentage of fine particles and/or coarse particles. Usually, the performance and appearance of reclaimed powder is inferior to the virgin material. As a result, the virgin material and reclaim materials are blended to provide satisfactory results. The blend ratio can be 50/50 or it may be a higher percentage of virgin, depending on the performance characteristics of a particular material. In some cases, after the same material has been recirculated several times, the reclaim powder can become saturated with fines and the performance becomes so poor that the material must be scraped.
- Compressed Air Consumption - Compressed air cost money to generate. Having the guns on only when parts are present reduces air consumption.
- Wear on Gun Parts - Surfaces in the powder delivery path are abraded by the sharp edges of the particles. Less spraying means less wear and less replacement of parts.

Other Gun Control Features

The same microprocessor based system that controls the gun triggering can be used to provide a variety of other functions. Specific gun settings and gun movement can be altered to provide precise adjustment for the needs of a particular part. Features that can be controlled include:

- Voltage
- Air pressure
- Stroke speed of the gun mover
- Stroke distance (up/down, in/out, side to side)

Control over these variables can provide a much higher degree of efficiency from one part to another, reducing waste and improving product quality.

5 Selection of the Application Package

There are several factors that must be considered in determining the proper application package.

- The size and shape of the part
- The variety of parts to be run
- The variety of powder chemistry and colors to be run
- Desired film thickness
- Production output
- Design line speed
- Size of the product opening
- Available capital

The part size and configuration will determine the product opening into the booth. The maximum part size is also needed in the selection of the number of automatic guns and their placement, the selection of gun movers and gun attachments, or the determination of the number of manual operators in a particular system.

The correct number of guns for a particular application depends largely on the vertical surface to be coated but the shape of the part and the line speed are also factors. Basically, the number of guns should consider how much surface will be coated in a given time period and select enough guns to coat it without above average output per gun.

A “rule of thumb” formula for determining the number of guns required considers:

- Design Line Speed
- Coating Thickness Required
- Part Size

Product height x line speed x mil thickness x the number of sides needing guns, divided by difficulty factor, rounded up to an even number.
 Difficulty Factor: 240 extreme 300 medium 360 simple

Example:

$$\frac{60" \times 10 \text{ FPM} \times 1.5 \text{ mils} \times 2}{300} = 6 \text{ guns}$$

One pound of powder covers 192.3 sq. ft. at 1 mil thickness at 1.0 specific gravity and 100 % utilization. Factoring the variables of actual thickness, specific gravity of a particular powder and the actual transfer efficiency will provide an idea of the coverage that can be expected from a pound of powder.

Testing has shown that low outputs provide higher transfer efficiency. The powder charges better and is less likely to blow by the part or rebound off the surface. So in the selection of guns it is important to avoid using too few guns with high output per gun. Efficiency is improved with the correct number of guns that will allow the system to operate below 30 pounds of output per hour, per gun.

Proper performance in powder coating depends upon the powder particles having an electrostatic charge and the substrate being properly grounded. The charge on the powder particles will determine how well the powder adheres to the part and the rate of film build. As a charged layer of powder accumulates on the surface it develops a force which resists further deposition.

The rate of film build is also related to delivery pressure, gun to target distance, particle size, the time of exposure in the spray zone, gun voltage and the volume of the powder delivered.

- Generally, higher voltage will produce heavier films
- Gun to target distance should be 6" to 12". Generally, a closer position will produce a heavier film and possible back ionization
- If delivery pressure is too high it will blow powder past the part, if it is too low the powder will not get to the part, it will be pulled into the reclaim system.
- A coarser grind of powder will produce a thicker film
- The rate of film build diminishes with longer exposure, however there is still an increase of film with prolonged exposure
- Typically, a larger volume of powder delivered will result in quicker film build

This does not necessarily mean that there is greater transfer efficiency. If a larger volume is delivered the percentage of efficiency may remain the same or decline, applying more powder but also over-spraying more powder. In addition, since a larger volume of powder sprayed will mean more cumulative charge on the part surface in less time there is a greater risk of back ionization when larger volumes of powder are sprayed.

6 Control of Powder Spray Application Equipment

The forces that influence the powder output and charge are the delivery system and the charging system. The delivery system transfers the powder from the container to the gun tip and out of the spray gun. The charging system charges the powder material so that it will be attracted to the part and stick to the part surface until it is cured.

Pneumatic Controls

Typically there are three air pressure controls; fluidizing air, powder supply air and powder atomizing air. Some guns will also have another air control at the gun tip to provide shaping or electrode cleansing air. The settings of these controls will influence the amount of powder that is delivered, the velocity that it is delivered at, and the uniformity of the powder cloud. This in turn will have profound impact on the transfer efficiency and quality of the parts.

Fluidizing Air

Fluidizing air is supplied to the bottom of the feed hopper to suspend and mix the powder, making it easier for the lift venturi to pull powder out of the hopper. If the powder has geysers and bubbles the air pressure is too high. If the powder rolls over lazily and unevenly the air pressure is too low. Properly fluidized powder looks like water at a low boil, in motion, with a fairly even surface. Incorrect fluidizing pressure can lead to an inconsistent delivery of powder at the gun tip.

If adjustments to air pressure do not produce proper fluidization, the separating membrane may be damaged by oil or moisture in the air-line. All air supplied to a powder system must be clean and dry.

Powder Supply Air

The powder supply air hose is attached to the lift venturi. The air passes through the venturi creating a vacuum that pulls powder out of the feed hopper or powder box. Adjustment to the pressure will control the volume and delivery velocity of the powder. This is the first

adjustment made to the gun. With the atomizing air off, the powder flow is adjusted up to a typical number, say 20 to 25 PSI. The powder will come out of the gun barrel unevenly until atomizing air is added.

Atomizing Air

The atomizing air is increased from zero to a level that is satisfactory to provide a smooth and uniform powder pattern. Care must be taken to avoid excessive atomizing air. Its purpose is to provide the energy to distribute the powder and transport it through the powder hose. Too much atomizing air will deliver the powder at a velocity that will produce excessive overspray and rebound from the part surface. Typically, the atomizing air is the same as or lower than the delivery air. After the atomizing air is adjusted, it may be necessary to slightly increase the flow air in order to compensate for backpressure created by the atomizing air source.

Cleansing or Shaping Air

Some manufacturers have an additional air supply at the gun tip for keeping the electrode clean or for shaping the pattern of the powder. This can be helpful for keeping the electrode from building up with impact fusion. It is especially useful when spraying metallics because of the tendency for metal flakes to build up on the electrode.

Venturi Lift Pumps

The venturi lift pump takes the powder out of the fluidized feed hopper or powder box, atomizes it and delivers it to the gun tip in a controlled and even pattern. A good venturi pump has a minimum of parts, is easy to remove from the hopper and is lined inside with inexpensive replaceable plastic inserts. These inserts need to be examined frequently and replaced when the hole-size enlarges and forces higher flow rates in order to maintain the desired powder output.

Air Pressure & Transfer Efficiency

Powder coating equipment manufacturers have all worked on reducing the delivery pressures to provide higher charging efficiency. Typical powder supply air pressures may range from 10 to 40 PSI. Atomizing air should be adjusted to a level that provides a uniform spray pattern from the gun. Lower air pressures improve the process.

- The powder charges better because it has more exposure to the corona field.
- The equipment life is improved because the powder is less abrasive at lower velocities.
- Lower pressure typically produces better transfer efficiency and less overspray. This means that less powder is cycled to reclaim.
- Film thickness and consistency is easier to control.
- Lower film thickness means improved cost and less orange peel.

Control of Powder Feed by Volume

Another powder delivery feature is control over powder flow rate measured in volume. There are metering systems, such as the auger feed system, that can measure the powder flow by grams or ounces per minute and compensate for variations in plant air use, fluid bed level, movement of the gun and hoses and other variations. These systems make corrections continuously to assure a uniform volume of powder delivery, controlling the powder flow too much a tighter degree than a standard venturi pump. This can provide better control over film build and return excellent material savings in operations that are routinely applying heavy films.

Voltage Controls

Corona charging guns have adjustable levels of voltage from 30 to 100 kilovolts. Variables in the application process, such as the powder material, the part being coated, the gun-to-target distance, will react differently to various levels of voltage and current draw. There is an optimum current level for the best possible first-pass transfer efficiency (FPTE) with a given set of variables. Typically, 10 to 20 μA (microamps) of gun current is the optimum range for the highest level of transfer efficiency. The lower current levels will help with penetration of Faraday cage areas. Flatter surfaces can be coated with the higher gun current level of 20 μA .

As the space between the gun and the part is reduced, the voltage will decrease and the current draw will increase. As the gun current level increases above the optimum level, more ions are created in the space between the gun and the part. The extra ions flow to the substrate at a much faster rate than the powder particles and quickly add charge to the surface, contributing to rapid development of back ionization.

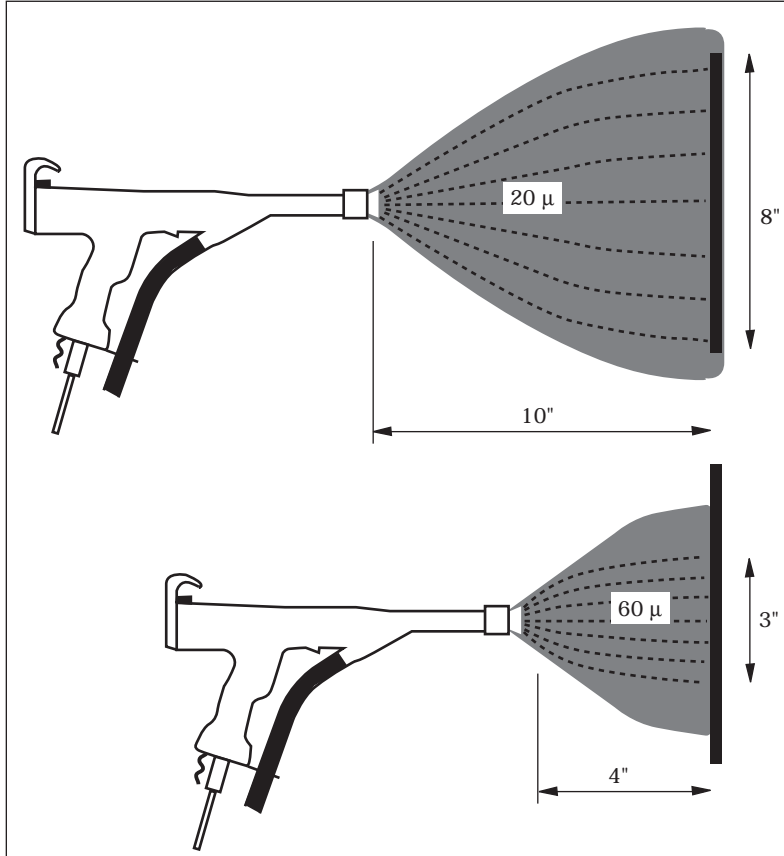


Figure 3-19 – Charge-to-Surface Ratio

There is an important relationship: the current-to-surface ratio. The more concentrated the free ions are on a part surface, the more likely they are to create application problems. If a spray gun is moved closer to the surface the current draw will increase and the part surface will have more free ions. To make things even more difficult, the amount of surface that is being contacted by the field lines will be narrower when the electrode is closer to the surface so the excess free ions will be concentrated in a small area.

Notice in the figure on page III/36 how the field lines are concentrated in a smaller area when the gun comes closer to the part surface. This can cause rapid back ionization and application problems, especially considering that the current will increase and add more free ions when the gun moves closer. This can be expressed in the following equation.

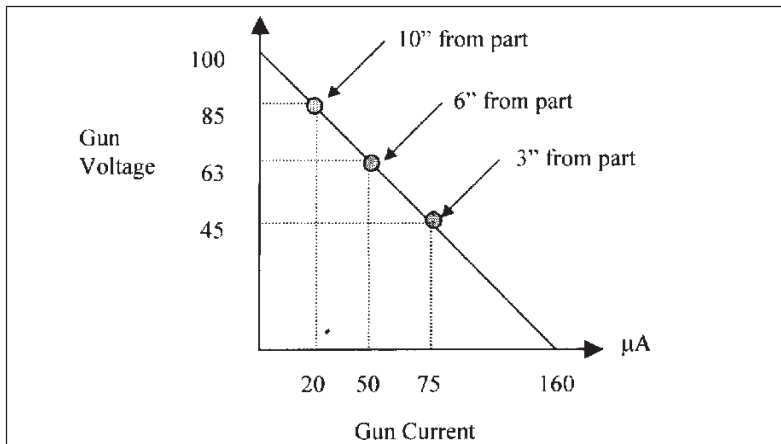
$$\begin{array}{l} \text{With a gun-to-part} \\ \text{distance of 10"} \\ \frac{20 (\mu\text{A})}{8 (\text{Sq. in.})} \end{array}$$

$$\begin{array}{l} \text{With a gun-to-part} \\ \text{distance of 3"} \\ \frac{60 (\mu\text{A})}{3 (\text{Sq. in.})} \end{array}$$

As the equation illustrates, the amount of current is greater and the amount of surface is less. Thus the amount of charge on the surface is significantly greater at close gun-to-target distances.

With automatic application equipment, the voltage adjustment can be set and the current level will remain stable as long as the part geometry is not too irregular. If the part geometry is irregular, current may vary. In manual operations, the sprayer moves the gun in and out and the resulting current level varies considerably. In many cases, manual operators will come very close to the part surface and increase current well beyond the optimum level for good FPTE.

Figure 3-20 – Conventional Load Line of a Corona Charging Spray Gun



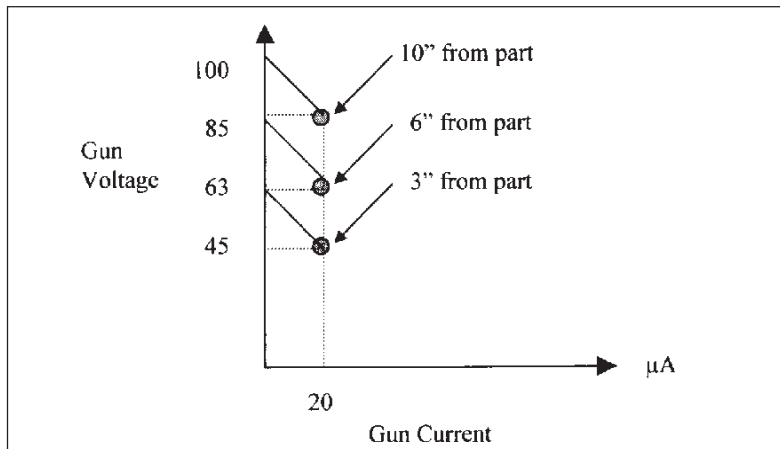
Excess current and the large number of free ions that it generates creates the problems that are commonly associated with the corona gun and coating deposition. Gun manufacturers offer some devices to help prevent excess current draw and the rapid back ionization that can occur. Current limiting can be a feature of the gun controls and operate automatically or it can be accomplished with fixed ion collectors.

Automatic Gun-Current Control

Automatic control of the gun-current allows you to set an optimum current level and maintain it, regardless of the gun-to-target distance. The control unit will automatically adjust the gun current output to maintain a consistent level that provides the maximum transfer efficiency. By controlling the current level to an optimum level, back ionization is delayed, the finish is smoother and more uniform, and FPTE is improved.

The automatic control of the gun current helps reduce the generation of an excessive number of free ions and controls the field strength at the part surface. It reduces the voltage at the gun tip when the electrode gets closer to the surface and helps provide better coverage in Faraday cage areas.

Figure 3-21 – Load Line with Automatic Current Control



With the current draw controlled automatically, the load line reacts to the resistivity of the circuit when the gun is moved in or out. The voltage is reduced and the current remains at a predetermined level.

It may appear that the reduction in voltage will also reduce the field strength and charging efficiency of the spray gun. Actually, if the gun is moved closer to the part and the voltage is reduced the field strength can remain the same.

$$\text{Field Strength} = \frac{\text{Voltage of the electrode}}{\text{Gun-to-target distance}}$$

Free-ion Collecting Devices

A free-ion collector is a grounded electrode that is mounted on the gun behind the charging electrode. The ion collecting electrode functions like the counter-electrode, preventing the free-ions from contributing to rapid surface charge on the part that causes back ionization. The ion collector is positioned closer to the charging electrode than the part surface. The electric field will follow the path of least resistance and develop between the gun electrode and the ion collector rather than between the electrode and the part. As a result, the electric field near the part surface will be created by the space charge of the powder particles as they arrive at the surface. This will be a weaker field than what would be generated if the free ions were allowed to flow to the part. However, if the powder has sufficient charge the transfer efficiency will not be seriously lower and penetration will be enhanced.

There is an important ratio between these two distances. The ion collector must be closer to the electrode than the grounded substrate to perform but if it is too close to the electrode it will reduce the charging area to a point where charging efficiency will suffer. A typical starting point is to position the ion collector about one half the distance between the electrode and the part.

In addition to providing improved Faraday cage penetration, a properly installed ion collector will help to avoid back ionization when recoating parts.

Because of the sensitive nature of the ratio of distance between the electrode tip, the ion collector, and the part surface, they are not

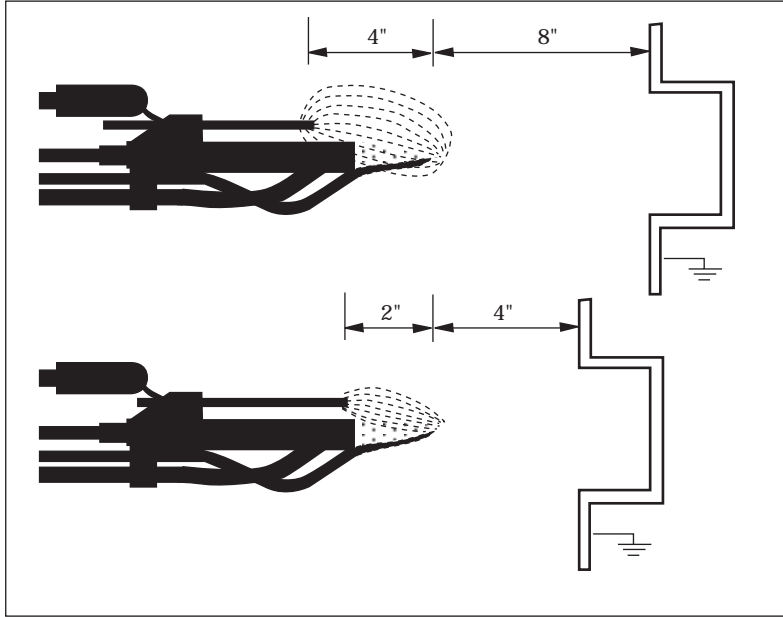


Figure 3-22 – Adjustable Ion Collector

equally effective in all situations. The area around the gun tip, that has a densely packed concentration of free ions available for charging, is shorter if the ion collector is too close to the electrode. The ion collector must be closer than the distance from the electrode and the part surface. At some point the ion collector will be too close to the gun tip and the charging zone will be so small that the time the powder particles spend passing through it will not be sufficient for the optimum charging efficiency and the overall transfer efficiency will be unacceptably low.

Powder Equipment Options

There are many options in the selection of application equipment. The correct charging method, the right combination of feed hoppers and gun movers are examples. Also, equipment options are available that can facilitate color change and help keep systems cleaner and more efficient.

Duplicate Equipment

Changing colors in powder is typically very time consuming, resulting in loss of production. One way to reduce the time required for color change is the use of duplicate equipment. Many times, the pay back for duplicate equipment is very short, due to the labor savings and improved production time. For example, many systems use different sets of hoses for lighter colors than they use for darker colors to save color change time and avoid cross contamination. Dedicated feed hoppers and cartridge modules provide the same convenience.

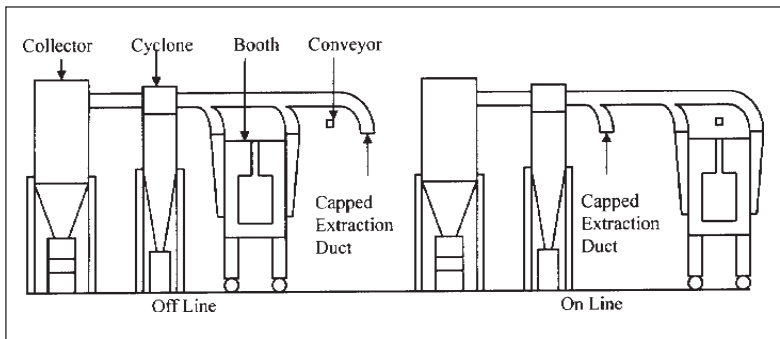
Because the overspray must be contained, the recovery system is one common place for duplicate equipment. These can be dedicated to a particular color and seldom cleaned, saving labor and lost production time. Guns and pumps can also be dedicated to a particular color, although this is typically not practical.

A very common practice is the use of two or more booths, installed in a roll on/roll off arrangement. The booths can be dedicated to a particular color or color changed while in the off-line position. This arrangement provides the fastest possible color change with the lowest risk of cross contamination.

Booth Movers

In most systems that use two booths, the booths have v-groove wheels that ride on a track to move them onto, or off, of the line. Movement of the booth is accomplished by pushing until the wheels hit a steel

Figure 3-23 – On/Off Line Duct Arrangement for Cyclone Recovery System (end view)



stop mounted at the end of the track. If the booth is too large to be moved manually, a powered booth mover can be installed to roll the booth on and off the line.

When a cartridge module booth is rolled off line, the entire assembly, booth, controls, guns and recovery system moves as one piece. With a cyclone type system, the extraction duct must have two connections. When the booth is on line, one connection is used and the other is capped. When you move the booth off line, the connections are reversed.

1 Powder Booths

A powder booth is an enclosure that is designed to contain the powder application process. A recovery system is attached to the powder booth shell. The recovery system uses a fan to pull air into the booth and prevent the oversprayed powder from migrating out of the enclosure.

The simplest powder booths are designed for a single operator to manually apply powder to a stationary product. Other booths are designed so that parts can be conveyed through the enclosure. Conveyorized systems may be designed for manual application from two sides, automatic application, or a combination of both, depending on the system requirements. The particular style, size and number of powder booths needed is related to the product size, the available space, the amount of capital and the volume of product to be coated.

Powder booth shells are occasionally made of painted steel but more often they are made of stainless steel, polypropylene, polycarbonate or other clear plastic, and a few are made of glass or polyethylene sheet. Painted steel is adequate but there is some risk that the paint will chip off and contaminate the oversprayed powder in the reclaim system. Stainless steel makes a very durable booth shell with a smooth surface for ease of cleaning. Plastic walled booths offer an easy to clean surface and the walls can allow some light to penetrate into the spray area and help illuminate the process. A nonconductive plastic walled booth will collect less charged powder on the walls. This means that they can be easier to clean. It also means that they do not attract as much powder that might otherwise be attracted to the part, so they provide a modest improvement in transfer efficiency.

The part size will influence the height and width of the booth and the required product opening. The opening size must allow the part to enter with proper clearance around the edges. In most cases, the clearance is 6" between the largest part and the edges of the opening. In a conveyorized system, the booth shell should extend at least 18" above the opening to keep the hook site well above the spray zone.

The amount of opening in the booth will determine powder containment air requirements. In order to contain the oversprayed powder, the collector fan is designed to provide 100-120 lineal feet per minute

IV

(lfpm) of air velocity across all openings. Properly designed, the booth will have even airflow throughout the enclosure and not interfere with the coating process. Collector fan sizing must also consider safety. Each powder is rated with a lower explosion level (LEL) measured in oz/ft³. The booth must be designed with enough ventilation to keep the powder concentration level below 50% of the LEL. The number of guns and nominal powder output per gun determines concentration.

The formula below shows the method of calculating the air requirements for a powder booth using a design face velocity of 120 feet per minute. The face velocity must be maintained at or above 100 feet per minute to ensure powder containment. The face velocity times the square feet of opening equals the fan size in cubic feet per minute.

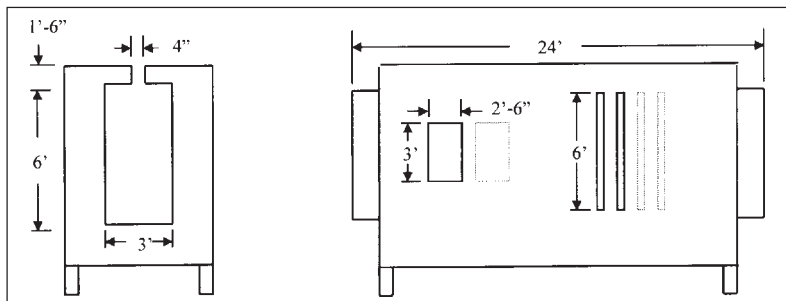


Figure 4-1 - Powder Booth Canopy Openings

1. Containment Air:

| | | | |
|--------------------|-------------------|---|--|
| Part Opening: | 6'-0" x 3'-0" x 2 | = | 36 ft ² |
| Touch-Up Openings: | 3'-0" x 2'-6" x 2 | = | 15 ft ² |
| Conveyor Slot: | 24'-0" x 4" x 1 | = | 8 ft ² |
| Gun Slots: | 6'-0" x 4" x 4 | = | 8 ft ² |
| Key Slot: | 1'-6" x 4" x 2 | = | 1 ft ² |
| Total Openings: | | = | 68 ft ² (= 6.3 m ²) |

$$120 \text{ ft./min} \times 68 \text{ ft}^2 = 8,160 \text{ CFM}$$

$$(37 \text{ m/min.} \times 6.3 \text{ m}^2 = 233 \text{ CMM})$$

A second formula may be used to determine if the airflow is sufficient to provide enough air to keep the concentration of the powder in the air below 50% of the minimum explosive concentration (MEC) in ounces per cubic feet or grams per cubic meter. The MEC of a particular powder can usually be obtained from the manufacturer. The table below provides test data on typical powders.

| Powder Type | Sample Number | English Units | | Metric Units | |
|-------------|---------------|------------------------------|-------------------------|------------------------|--------------------------|
| | | MEC oz/1,000 ft ³ | Auto Ignition Temp (°F) | MEC gms/m ³ | Auto Ignition Temp. (°C) |
| Epoxy | 1 | - | - | - | - |
| | 2 | 45 | - | 45 | - |
| | 3 | 65 | - | 65 | - |
| | 4 | 39 | - | 39 | - |
| | 5 | 52 | - | 52 | - |
| | 6 | 46 | 925 | 46 | 496 |
| | 7 | 70 | 970 | 70 | 521 |
| | 8 | 97 | 998 | 97 | 537 |
| | 9 | 91 | 1002 | 91 | 539 |
| | 10 | 78 | 993 | 78 | 534 |
| | 11 | 78 | 1024 | 78 | 551 |
| Polyester | 1 | 65 | 795 | 65 | 424 |
| | 2 | 71 | 700 | 71 | 439 |
| Polyolefin | 1 | 32 | - | 32 | - |
| | 2 | 32 | 960 | 32 | 516 |

In the above example, the booth is sized by the containment air requirement. Since the containment air is almost always greater than the safety air requirement, booth manufacturers rely on face velocity to determine the fan size.

Batch booths for manual operations are made in many standard sizes, such as a lab type booth of approximately 4' x 4' (1.2 m x 1.2 m). They can also be constructed to fit virtually any product size.

For conveyORIZED systems, the product opening size is determined by the largest part to be run through the system. Six inches (15 centimeters) of clearance is allowed around all sides of the largest part through the product opening.

Another factor that influences the size of the booth is the need to keep the hanger point out of the spray zone. The hanger point is the top of the rack that attaches to the conveyor hanger. If the rack or the conveyor is in the spray zone and powder collects on the metal sur-

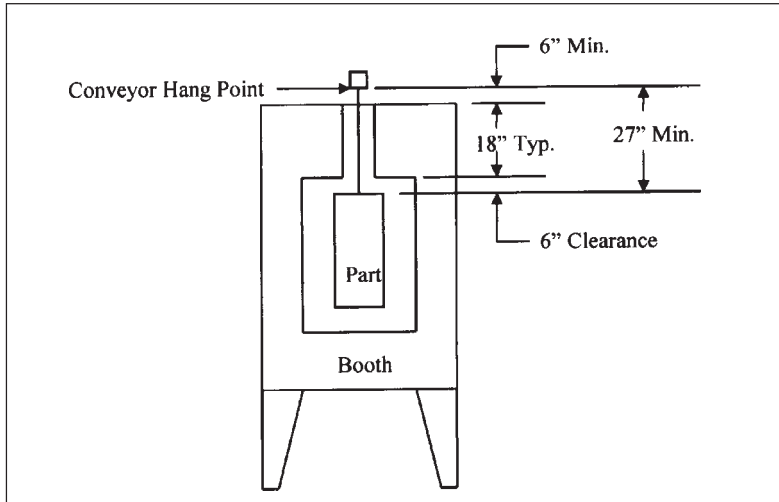


Figure 4-2 - Hanger Length

face it will cure in the oven and insulate the hanger point from ground. The importance of maintaining a proper earth ground cannot be over-emphasized. Without a good ground, it is much more difficult to get the powder on the part in an even pattern and very difficult to penetrate Faraday areas.

The hanger length from the hang point to the top of the parts being coated should be a minimum of 27" (69 centimeters). This is long enough to provide ample clearance between the conveyor hang point and the spray zone.

The booth canopy must be wide enough to provide ample space between the gun tip(s) and the part being coated. If the gun tip is not extended far enough from the wall the electrostatically charged powder may be attracted to the wall instead of part.

Lighting

It is critical to have good lighting inside the booth, especially for manual sprayers. If the operator cannot see the surface they will apply too much coating or not enough. Fluorescent fixtures should be installed horizontally in the ceiling of the booth and vertically alongside the manual stations. Lighting should be in accordance with National Fire

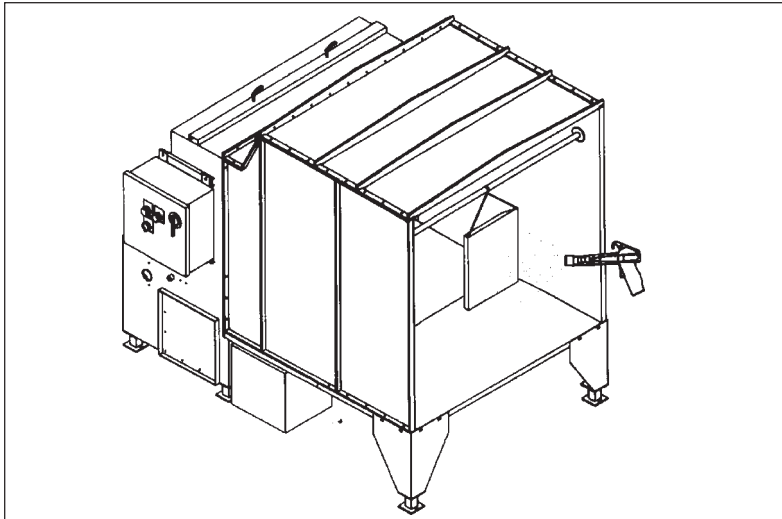
Protection Association (NFPA 33). Electrical lamps should be installed in the booth wall with a safety glass panel separating them from the inside of the spray area. Electrical lamps within 20' (6m) of the spray area should be Class I, Div. 2 to conform to NFPA 70, *National Electric Code*.

Air-Flow

The spray booth must have negative air pressure to contain the powder inside the booth. The airflow inside the booth must not be aggressive enough to compete with the part for the powder. Many "home-made" booths make the mistake of pulling the air through too small of an outlet that is too close to the application area. As a result, the airflow pulls powder away from the parts. The operator compensates by increasing their delivery pressure, generating excessive overspray and applying too much powder to the part.

Proper airflow requires a careful balance between the need to contain powder and the need to avoid turbulence inside the booth. The inlet to the reclaim system must be large enough and located far enough from the spray zone to avoid interference with the application process.

Figure 4-3 - Lab Booth



Manual Batch Booths

Small batch booths are manufactured for lab work and low volume production situations.

The lab booth has a comparatively small work area (typically around 4' x 4' opening) suitable for hanging sample panels or small parts. The recovery system is located at the back of the booth and the powder is sprayed to waste.

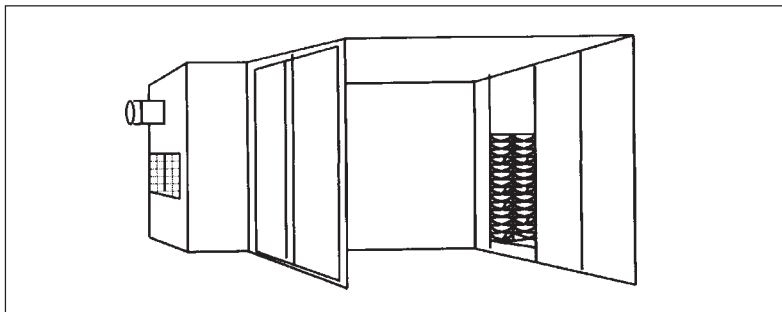
Walk-in manual booths are larger and can be used in production situations with or without a conveyor system. They are also typically used for non-reclaim situations. Walk-in booths are useful for large product that is not practical for hanging on a conveyORIZED system or for small volume operations. Walk in booths can be used with or without a conveyor system and sized for virtually any product.

Powder Booths for ConveyORIZED Systems

ConveyORIZED systems may be designed for manual application only, automatic application or a combination of the two. They are designed for continuous application with parts traveling through on a conveyor system. ConveyORIZED booths provide an opportunity for higher volume production without the handling issues associated with batch operations.

The booth will have a shell with a part opening on each end and openings for the application equipment on the side. The recovery system will be designed to capture the powder for reuse or disposal.

Figure 4-4 - Manual Walk-in Booth



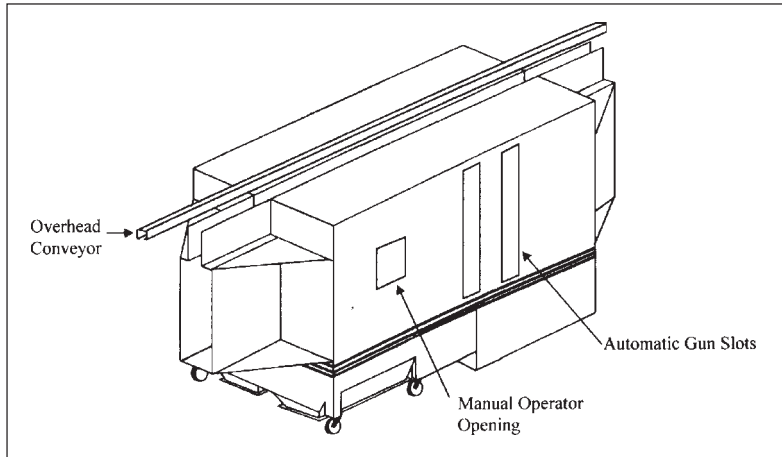


Figure 4-5 – Powder Booth for ConveyORIZED System

Many powder coating systems are designed for two manual operators, one on each side of the booth. The operator openings are staggered to avoid spraying directly across from each other. A platform is mounted under the manual opening to raise the operator to the proper level. A slot at the top of the booth allows the hanger to be suspended into the spray zone. The conveyor hang point is a minimum of 6" above the booth ceiling.

The same basic booth configuration can be designed for automatic application only. Instead of manual openings on the sides it will have slots for the automatic guns. In the United States, automatic systems always require a fire detection system to disable the equipment if a fire is detected. The flame detection system provides protection against fire. If a flame, spark or arc occurs, the system either warns the operator or turns the powder supply and the power off so that there is no fuel for a serious fire.

Automatic application can be 100% effective but most booths that are designed for automatic application will also have manual stations for reinforcement.

The openings for the application should be positioned far enough from the collector fan to avoid aggressive airflows. If the powder is

sprayed too close to the collector it may not get to the part before the aerodynamics of the recovery system pull it away. A comparison of two booths of different length should consider the position of the reclaim inlet. A shorter booth may appear to be an advantage because it will take up less space. However, a shorter booth will also mean the powder will be sprayed closer to the pull of the reclaim airflow.

2 Recovery Systems

Powder booths utilize a fan assembly with a protective filter section and a containment vessel to pull air into the booth. This system, called a recovery system, captures the oversprayed powder for reuse or disposal.

The recovery system provides the necessary containment and safety air, and recovers the oversprayed powder. Properly designed systems have a primary filter and a secondary filter, commonly referred to as the final filter. The first filter is used to separate the oversprayed powder from the air for reclaim and the final filter is used to remove any particles that have passed through the primary filter, keeping the working environment free of powder particles. Commonly used recovery systems include the cyclone system, the filter belt booth, the cartridge module system, mini-cyclone systems and sometime systems that combine technologies in the same booth.

Cyclone Recovery Systems

The original powder booth was designed with a cyclone as the main component in the recovery system. The cyclone is used as a separator to classify powder by particle size. The larger particles are collected in the cyclone for reuse and the super fine particles pass through the cyclone to the cartridge collector for scrap.

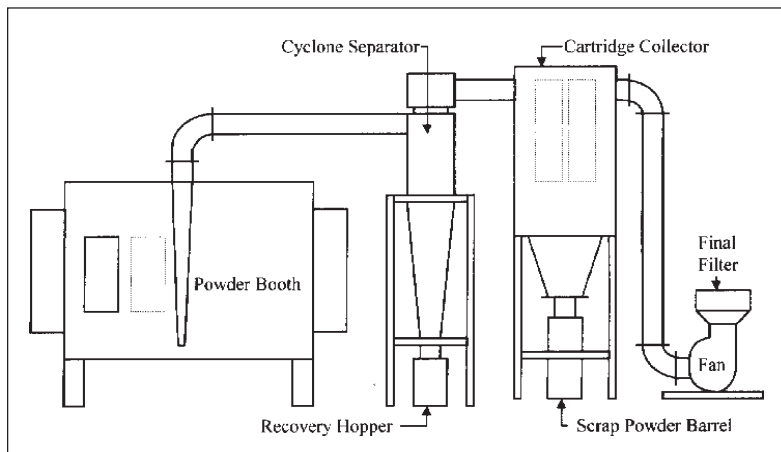
The overspray powder is drawn to the extraction duct of the booth by airflow from the recovery system fan pack. This airflow is generated by a blower that creates a vacuum in the booth through a ductwork system. The ductwork from the booth is connected to a cyclone, used as the primary means of powder separation and recovery. The powder and air mixture enters the cyclone at a typical velocity of 60 feet per second (fps), and the cylindrical shape of the cyclone influences the powder/air mixture to turn centrifugally, with the powder parti-

cles dropping out to the reclaim canister located at the bottom of the cyclone. This reclaimed powder can be automatically transferred back to the feed hopper or the canister can be removed and dumped on a periodic basis. It is a good idea to put the recovered powder through a sieve to remove dirt.

The relatively clean air coming from the top of the cyclone is drawn into a cartridge collector or baghouse for secondary separation. Depending on the powder and the cyclone design, 3 to 10% of the recovered powder is pulled past the cyclone to the collector. This powder is separated from the air by filters in the collector. The filters are back-pulsed periodically to dislodge the powder and drop it to the waste canister at the bottom of the collector. The clean air from the collector is blown back into the room through a final filter.

The main advantage of this type of recovery system is the ability to spray an unlimited number of colors without the need for additional equipment. Overall material utilization is somewhat lower than cartridge module systems because some powder is separated out to waste. As mentioned before, this separation is related to powder particle size. The spinning in the cyclone takes the larger particles to the reclaim canister while the very fine particles (< 20 micron) are pulled through to the collector.

Figure 4-6 – Cyclone Recovery System

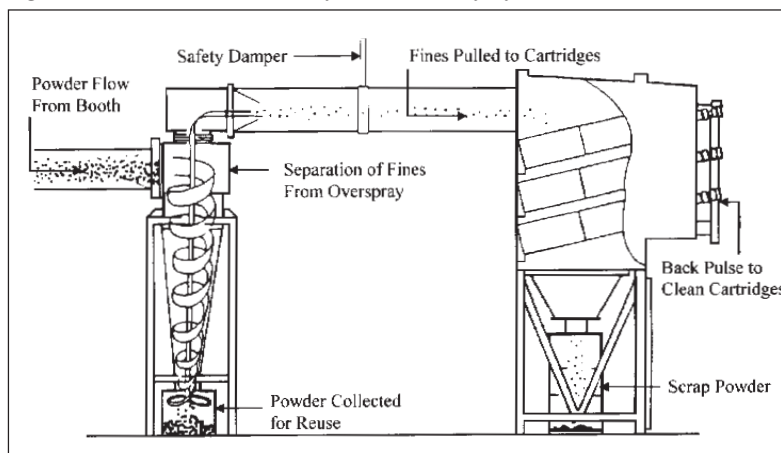


Although cyclone systems have the advantage of allowing the operator to run multiple colors without duplication of equipment, some of the major manufacturers have not promoted them due to the safety regulations required for enclosed vessels. Safety dampers and explosion relief venting are required by NFPA. Also, the ductwork used to connect the components of the cyclone system may have traces of impact fused powder left after color change, creating a somewhat greater risk of cross contamination.

The traditional large-body cyclone system delivers an overall material utilization percentage that is less than cartridge module systems. The powder that is separated from the volume that is sprayed is typically around 6 to 10%. When the recovered powder is sprayed the same loss occurs once again, reducing the overall material utilization by a further percentage. The overall material utilization must account for this cumulative loss. If first time transfer efficiency (FPTE) is very high the material utilization may be pretty good. If first pass transfer efficiency is poor the material utilization will be much lower.

The typical overall material utilization in a cyclone system ranges from 70 to 90%, compared to a cartridge module system which can deliver 90 to 97%.

Figure 4-7 - Powder Flow in a Cyclone Recovery System



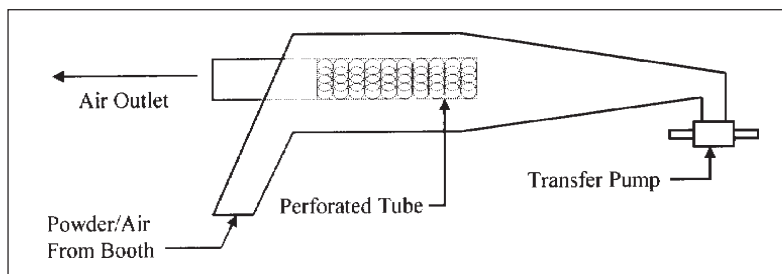


Figure 4-8 – Cyclo-Kinetic™ Separator
(Courtesy of Nordson Corporation)

Recently, cyclone systems have been developed that use the same inertial separation technique as the traditional cyclone system with a different configuration that addresses some of the problems associated with the original systems. These systems are safer and more efficient and they still provide the ability to run multiple colors without dedicated collection equipment.

One such system uses a series of horizontally mounted cyclones. Oversprayed powder is drawn into the separators and removed from the fan air stream by centrifugal force. A pump at the end of each cyclone returns the powder to the feed hopper. The fan air is pulled through cartridges to ensure removal of any remaining particulate and then it is discharged back into the room through a final filter. The small cyclones can be easily accessed and cleaned by opening the end, eliminating the risk of cross contamination.

Another of this new breed of mini-cyclone systems uses a series of small, vertically mounted cyclones. Each cyclone has a series of vanes mounted near the top that help to direct airflow in a downward spiral inside of the cyclones. An "Autodamper" system controls the airflow through the unit by adjusting for system variables. The powder-laden air passes through the cyclones into the collection unit. From there it can be transferred back to the feed hopper or into another receptacle. The air and a small volume of residual powder is carried on into the cartridge collector and discharged back into the building through a final filter.

This system can be color changed without the need for dedicated equipment. For additional flexibility, the cyclone unit can be disabled

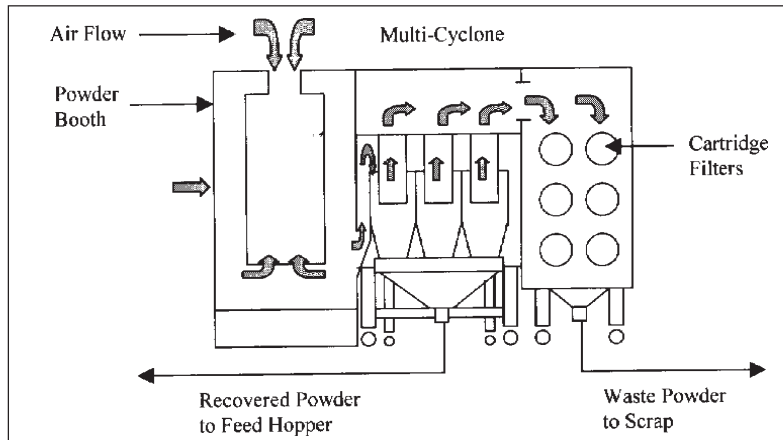


Figure 4-9 – Vortech™ Multi-Cyclone Recovery System
(Courtesy of ITW Gema)

and the overspray carried directly to the cartridge module unit. This allows the operator to run short runs of various colors without contaminating the cyclones, providing faster color change times for low volume runs and samples.

Filter-Belt Recovery System

The filter-belt system is often called a twin-air-belt system. It uses two air circuits; one for containment and one for reclaim. The containment air is used to provide a down draft airflow and draw the oversprayed powder particles to a horizontal rotating fabric material called a filter belt. A main exhaust blower creates a vacuum through a plenum area underneath the belt that draws the powder to it. This airflow provides the high volume, low vacuum air required to keep the powder particles inside the booth cabin and provide the necessary safety air ventilation. The filter media separates up to 99% of the powder from the air. This air is exhausted back into the plant through a final filter.

The reclaim air is used to vacuum the powder off the filter belt for reuse. This low volume, high vacuum air is generated by the reclaim exhauster. The pick-up head is a long slotted tube that extends across the entire width of the belt. The powder is conveyed through a con-

necting hose to the reclaim cycart. The cycart contains filters for secondary powder separation. The powder that collects on the filters is back pulsed and released into the rotary feeder. The rotary feeder is used to regulate the amount of powder flow into the sieve and maintain the vacuum in the cycart.

Fresh powder is fed into the system in a similar fashion. The fresh feed exhauster draws the material from the powder container into a separate cycart assembly. This powder is also back pulsed into a rotary feeder. The reclaimed and fresh powder is mixed through a "Y" diverter into a sieve. The sieve filters the powder and provides a consistent mixture of powder particles to the hopper.

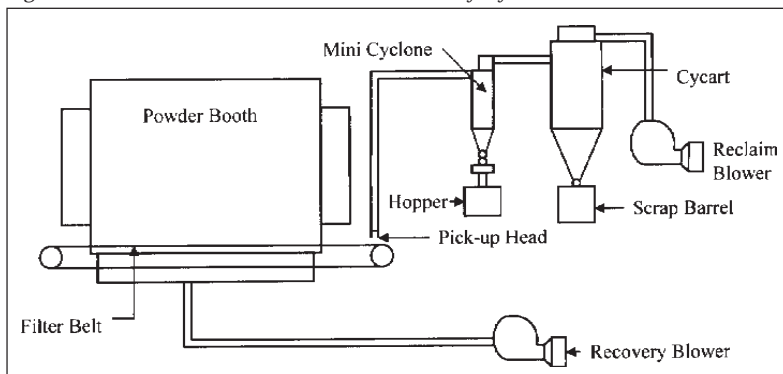
Because of the large surface area of the belt, air velocities inside the booth are modest, enhancing transfer efficiency. The air belt is difficult to color change. The possibility of cross contamination is greater with the filter belt booth unless dedicated belts are used.

Cartridge Recovery Systems

The self-contained cartridge module recovery system is the most common type of recovery system used in the United States.

This type of system uses replaceable cartridge filters for the primary powder separation. These cartridge elements are typically made of corrugated material to increase the available surface area for filtration.

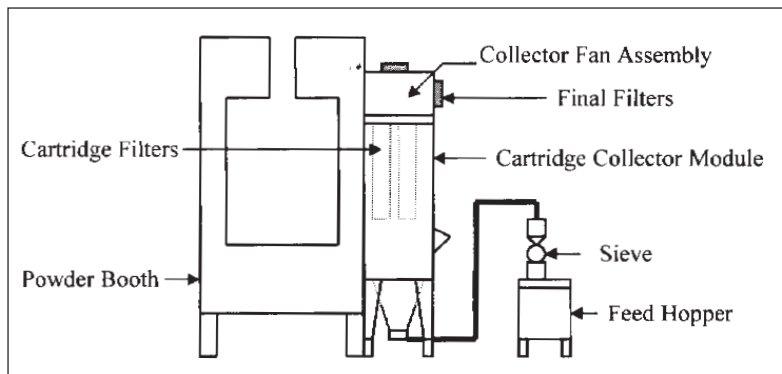
Figure 4-10 - Multicolor Twin Air Belt Recovery System



The collector and blower assembly is mounted directly to the booth without any connecting ductwork. In the configuration shown, the airflow is in a side draft or horizontal direction. Oversprayed powder is drawn to the filter cartridges by the exhaust fan. The air that is drawn through the cartridge filters is then exhausted through a set of final filters for secondary filtration to ensure that no particulate is discharged back into the plant. The powder collected on the cartridge filters is back pulsed through an alternating sequence that drops the particles to the bottom of the collector. A fluidizing section in the base of the collector provides the powder consistency needed to transfer it back to the reclaim canister. In most cases, virgin powder is added into the reclaim module through a chute. The fresh material is mixed with reclaim material in the cartridge module and then filtered through a sieve before being fed back into the hopper.

The cartridge module can be used for multiple colors in a spray-to-waste system. If a color is to be for reuse, the cartridge module is rolled out and replaced with a new module that is dedicated to the new color to be sprayed. If the powder material is one of several low-volume colors it may be sprayed into a module that collects all of the low-volume materials together. Most of the time this mixed material is thrown away. In a few cases, companies with parts that need to be coated but are not color-specific will use the mixed material for this kind of product.

Figure 4-11 – Cartridge Recovery System



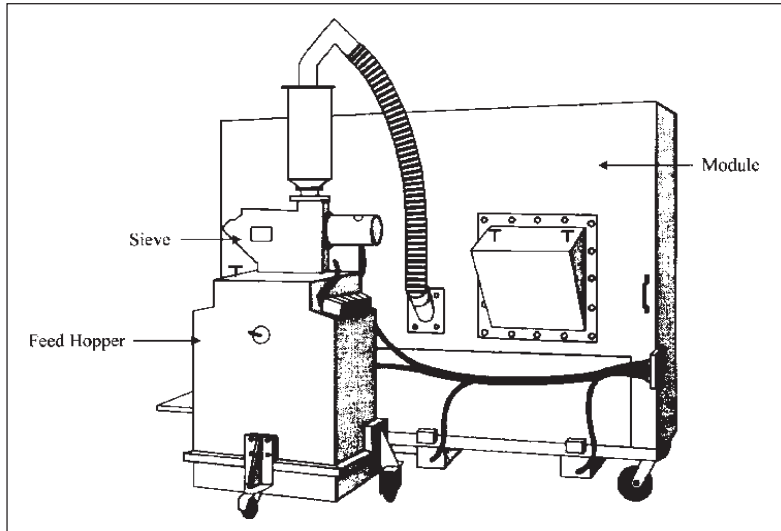


Figure 4-12 – Cartridge Collector Module

For spray-to-waste systems with automatic guns, multiple feed hoppers of different sizes are recommended. Some may be dedicated to a particular color and some may be used for color changes of small-volume colors or very short runs. Feed hoppers come in many sizes. Smaller canisters, 50 to 80 pounds, are much simpler to color change than the large feed hoppers from 100 to 250 pounds.

In systems where the overspray is collected for reuse, the recovery package will include a dedicated module and feed hopper. Most systems will also include a sieve to remove dirt and other contamination from the reclaimed powder. Accumulated dirt and fiber will collect around the gun tip if the powder is not sieved, causing clumping of the powder around the electrode and gun spits.

Cartridge Recovery System Air Flow

The containment air flows through the cartridges carrying powder and depositing it on the cartridges. The compressed air blow pipe discharges on a sequenced basis and the powder falls to the base of the collector.

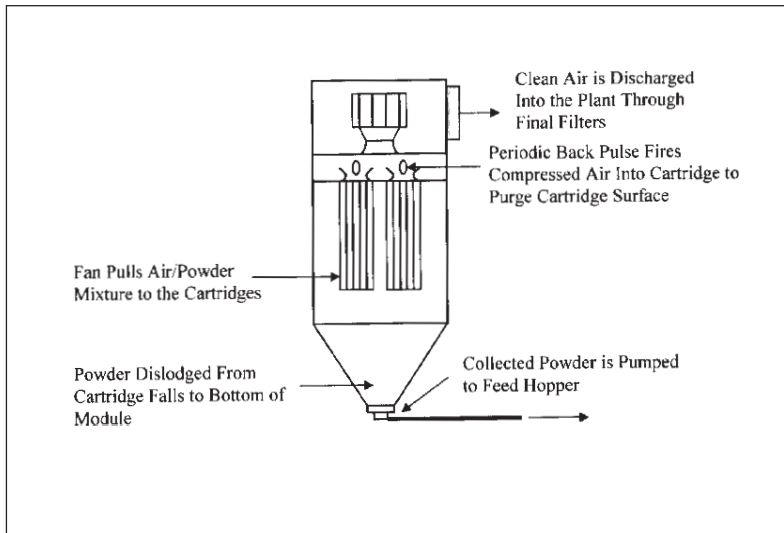


Figure 4-13 – Airflow in a Cartridge System

Combination Cyclone/Cartridge Module Booth

There are booths available that combine some of the advantages of the cyclone system with the advantages of the module reclaim system. The theory with this design is to give the operator flexibility and efficiency in one booth.

The cyclone system can be used for short runs of various colors and the overspray can be captured for reuse or scrap. For larger volume colors, a cartridge module can be used to take advantage of the higher reclaim percentage or one module can be used to collect small volumes of various colors.

For installations that use only one booth this is an excellent alternative. The high efficiency of the module is available as well as the ability to collect any number of colors for reuse without the need for additional equipment.

Selection Criteria

Each type of recovery system has advantages depending on the application. The major selection criteria are available space, color change

requirements, airflow characteristics, powder utilization, capital equipment cost, and operating costs.

Available Space - One important criteria when selecting a powder system is the available floor space and height restrictions. The cartridge recovery system is typically the most compact design in floor space requirements, however, due to the collector and blower being mounted directly to the booth, each color to be recovered will require its own module, adding to the cost and space requirements. The cyclone system requires more headroom because the cyclone and cartridge collector stands much higher than the booth. The floor space required for this system is greater because the cyclone and final filter are remotely mounted using interconnecting ductwork.

The twin air belt system does not require the headroom of either the cartridge or cyclone system because the floor can be closer to the ground than other systems. The floor space required for the filter belt design can be greater than a cartridge system due to the remote reclaim system. However, the reclaim system can be located in an open area away from the booth providing layout flexibility.

Color Change Requirements - The actual time required to change colors in any of these booths depends on the quality of finish required, how many people work on it, number of powder guns, the size of the booth and the amount of duplicate equipment for dedicated colors.

The cost and time required to color change can vary drastically between the different recovery systems. To reclaim each color in a cartridge booth, a dedicated collector is required. With a cyclone system or a filter belt booth using the cyclone or mini-cyclone, multiple colors can be reclaimed without any additional equipment.

An average cartridge system takes 30 to 60 minutes to change, the cyclone system takes 30 to 90 minutes and the twin air belt takes 60 to 120 minutes to change over.

The other important factor to consider on color change is the number of colors and the interval between color change. If the time between color changes is long and the number of colors is few, the cartridge module system makes sense because it will provide the highest potential reclaim percentage. When the time between color changes is short, or there are a lot of colors, then the cyclone system becomes more practical.

The cartridge system is less practical when there are many colors required due to the added cost in dedicated color modules. The cyclone system is better when many colors are run for short intervals because there is no need for additional recovery equipment. The twin-air-belt system is difficult to color change, making it impractical for most multi-color systems.

Lines with two or more booths can change colors with a minimum of production loss. One booth can be prepared for another color off-line while the second booth is in production.

Powder Utilization - Although there is some powder loss in a cyclone system, a well-designed system can provide 70% to 90% material utilization. Typical utilization for the filter belt using a mini-cyclone is 85-95%. In a cartridge module system, there is virtually no powder loss due to the nature of the recovery design. These systems typically provide from 90 to 98% overall material utilization.

Always keep in mind in any economic evaluation that there is a certain amount of loss on racks and in handling. Also, testing has shown that the fine particles (less than 20 micron) of powder do not contribute much to the film. So as the percentage of fines increases, the material will become less efficient. In some operations, it is necessary to periodically dispose of the powder in the cartridge module due to accumulation of fines.

To avoid excess accumulation of fines, the overspray should be consumed fast enough to maintain a low level of powder in the cartridge collector. In order to consume the oversprayed powder fast enough to avoid accumulation the first pass transfer efficiency (FPTE) must be near 50% or better. If the percent of overspray exceeds 50% the powder level in the collector will continue to rise when fresh material is added.

Capital Equipment Cost - The cyclone system and the cartridge system are close to the same cost until you add additional cartridge modules. For one color operation, the cartridge module is the lowest cost. Additional modules will add significantly to the cost. The twin air belt system is the most expensive type of system. System costs depend heavily on the number of colors required.

Operating Cost - The operating cost for a cartridge system can be higher than both the cyclone and twin air belt booths due to the amount

of compressed air used in the collector unit and more frequent replacement of cartridges. Compressed air is required to fluidize the powder in the bottom of the collector and provide the necessary pressure for back pulsing. The cartridges tend to wear a little faster because they are subjected to a higher volume of powder and more frequent back pulse at higher pressure.

In a filter belt system, you should also consider the electrical requirements for the addition of the reclaim exhauster and the belt drive.

The selection of a recovery system must consider all of the system requirements. All recovery systems have advantages and limitations.

Summary

The primary advantage of the cyclone system is the ability to run many colors without adding additional reclaim equipment. It is best suited to shorter runs of smaller volume. The disadvantages are a slightly lower material utilization percentage and some additional safety considerations.

The primary advantage of a cartridge module system is the highest possible material utilization percentage. All of the overspray is collected for reuse. The disadvantage is the need for a module for every color that is reclaimed for reuse.

The primary advantage of the filter belt booth is the potential for high transfer efficiency. This is due to the broad surface of the belt for exhaust air. The broad surface area allows the volume of air required for containment to spread out and moved at a very slow velocity so that it does not interfere with powder deposition.

Spray-to-Waste

Another option that is part of the consideration is spray-to-waste. In some operations with short runs of many colors it is not practical to invest the time and money into reclaim. Spray-to-waste can be done with a batch booth, cartridge booth or cyclone system. The powder is captured and disposed of instead of being recycled into the system.

Spray-to-waste is strictly an economic decision. The cost of equipment and labor for recovery is compared to the cost of the scrap powder.

IV

A system that does not reclaim powder can be color changed faster than a system that reuses overspray. The guns and feed system must be cleaned the same as the reclaim operation but the booth interior does not have to be cleaned as thoroughly and the recovery system does have be switched.

If automatic guns are used for spray-to-waste, multiple feed hopper may be required. Automatic guns are usually fed from a large feed hopper that is very difficult to color change. If the cost of dedicated feed hoppers is not practical, two 80 lb. canisters can be used, one for half of the automatic guns and one for the other half. This size of canister can be quickly emptied, dismantled and cleaned.

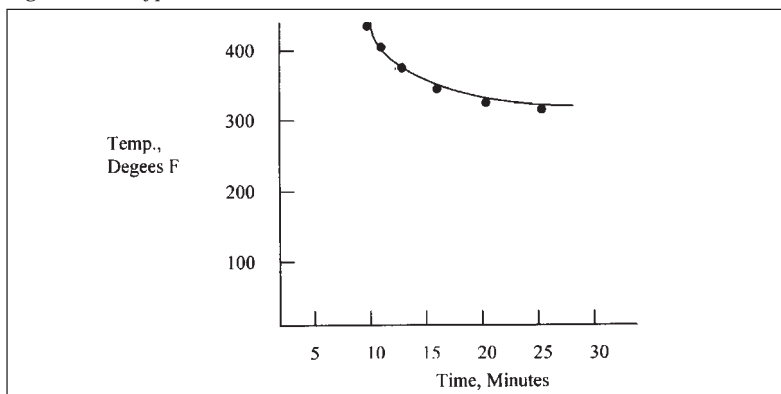
When a thermoset powder is exposed to elevated temperature, it will begin to melt. As the material begins to melt, it will flow out and then chemically react to form a higher molecular weight polymer in a network-like structure. This cure process, called crosslinking, requires a certain degree of temperature for a certain length of time in order to reach full cure and establish the full film properties that the material was designed for. The chart below shows a curve of time temperature relationship for a theoretical powder material. The powder would cure at any point on the curve from 10 minutes at 420 °F to 25 minutes at 320 °F (10 mins. at 215.6 °C to 25 mins. at 160 °C).

The application of energy to the product to be cured can be accomplished by convection cure ovens or infrared cure ovens.

1 Convection Cure Ovens

A convection oven uses a heat source, most commonly a gas burner, and a fan to heat the interior of an insulated enclosure. Different powder materials require different cure temperatures, commonly in a range between 350 °F and 400 °F (177 - 204 °C). The part is heated by the hot air in the oven and it in turn conducts heat into the coating. The coating must be held at temperature for a predetermined length of time to reach full cure. So the cure cycle is so many minutes at so

Figure 5-1 - Typical Cure Index



many degrees of temperature. The time it takes to bring the metal up to temperature must be added to the cure time requirement to determine the full cycle time in the oven.

Convection cure time may be as short as 10 minutes or as long as 30 minutes, depending on the mass of the substrate and the cure requirements of the powder. Convection curing is dependable and flexible. The oven can be adjusted along a full range of temperature requirements and the line speed can be adjusted for the time requirement. The part can be exposed for a longer period of time than what is called for, usually with no change in color, gloss or performance in the coating. Energy consumption is related to the load of product, the amount of insulation and the volume of exhaust. Typically, a gas-fired oven is very efficient and cost effective.

Materials

The oven interior skin should be aluminized steel because it has superior heat resistance over galvanized or cold rolled steel (CRS). The outside oven skin can be galvanized, aluminized or painted CRS. The steel should be 20 gauge thickness. All of the oven trim should be the same metal as the skin.

Insulation

The insulation should be No. 4 density mineral wool or equivalent fiberglass and the thickness should be 1" for every 100 °F (37.8 °C) or fraction of 100 °F. If an oven has a maximum rating of over 500 °F (260 °C), the oven panel should be 6" thick. The roof and walls should be the same panel thickness but the floor may be plain concrete, aluminized skin or insulated oven panel. Elevated ovens must have an insulated floor. Floor mounted ovens should have 2 to 3" (5 to 8 centimeters) of insulation. It is possible to use a steel skin with no insulation but there is significant heat loss through the floor.

Duct Design

Cure oven ductwork should be designed to circulate air in a way that will maintain even heat throughout the oven and not create turbulence. Excessive air velocity in the cure oven can cause powder to be blown off of parts. It can also cause parts to swing around and hit other parts or the walls of the oven.

The best location for the duct is the ceiling, located in the corners and between passes in a multiple pass oven, with the air directed down towards the floor. Discharge cones or nozzles are used to adjust the volume and velocity of air as it exits. With the return at the center, the air will circulate back up through the parts.

The floor is also an acceptable location, arranged under the conveyor with air passing up through the parts. However, floor duct will inhibit cleaning the oven interior and it is subject to damage if parts fall off the conveyor.

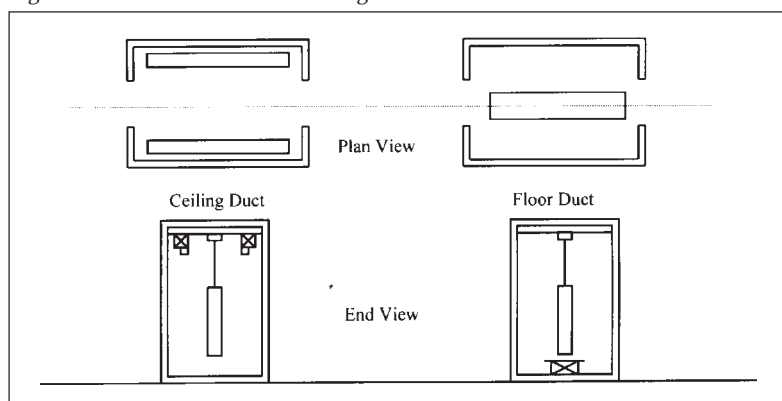
Unlike the dry-off oven, air impingement on the parts is not desirable in a cure oven. It may accelerate curing but it will also blow powder off the parts and can blow dirt onto them as well. High velocity should be avoided inside a powder cure oven.

Oven Size

The oven size will depend on the size and mass of the product to be run and the production volume. The oven must be sized to handle the largest part with enough burner capacity to handle the heaviest load of product.

A batch oven cycle time will typically be around 15 to 20 minutes. The oven interior should be big enough to handle 20 minutes worth of production. In some cases, two ovens are necessary to maintain a flow of work.

Figure 5-2 – Cure Oven Duct Arrangement



The interior size of an oven for a conveyORIZED system will depend on the largest part size and the production line speed. The actual length of the conveyor will be the cure time required plus the bring-up time of the substrate, times the line speed. If the metal of the part takes 5 minutes to bring up to the design temperature and the powder takes 15 minutes of cure time, the oven cycle time will be twenty minutes. If the line is travelling at 10 feet per minute (3 meters/min.) the oven will need 200 linear feet (60 meters) of conveyor.

bring-up time + cure time = cycle time

cycle time x line speed = length of conveyor in oven

Oven Balancing

Even air flow and temperature balance in a convection oven is important. If there are areas that are not even in temperature the coating may not be uniformly cured and color and gloss may vary. To make sure that the oven is evenly heated, a temperature recording device should be run through the oven at least once a month. Using several probes to read both air and part temperature from top to bottom, the operator can determine if any problems are likely to occur and where the temperature variance in the oven is located. They can also determine how long it takes to bring the metal to temperature so that the cure cycle time is known. Adjustments to the discharge ductwork can then be used to create even distribution of the oven energy supplied by the heat source and conveyor speed can be adjusted to provide the proper time in the oven.

2 Combination Dry-off/Cure Ovens

Some manufacturers offer a single oven with one route through for drying and one route for curing. This arrangement saves capital equipment cost and some manufacturers may claim that it saves energy. However, moisture drying and curing operations should not be done in the same oven. Moisture evaporation can affect the cure process and uncured powder can drift onto parts in the drying section and cause dirt defects. Air flow and temperature requirements for drying and curing are not the same.

As for energy savings, the amount of fuel required to dry and cure the parts will be the same regardless of whether it comes from one burner

or two. A dual-purpose oven with one burner box will require as much burner capacity and fan capacity as an oven with separate heat sources. In fact, a dual-purpose oven may cost more to operate because the dry-off temperature must be the same as the cure temperature. In many cases the dry-off oven temperature can be much lower than the cure temperature.

It is economical to build the two ovens side by side and separate them with a wall due to reduced radiant heat loss. They should always have their own fan, burner and controls to provide the best control of the process and the most effective results.

Fuel

Gas, electricity and steam can all be used to fuel process ovens. Which one to use depends on the cost of the fuel and the supply. If it available, natural gas or propane is by far the most economical fuel source.

Gas

Gas is most commonly used in process ovens because it is readily available; it is easy to control and typically cheaper than other fuels. A high quality gas burner has a 40:1 turn down ratio. This means that the oven burner output will respond to the conditions in the oven interior and modulate the volume of gas burned to provide the correct temperature.

The more product that is put through the oven, the more gas it will burn. When the oven has a light load or it is empty, the burner will modulate to low fire and idle until the thermocouple indicates a need for more Btu's.

The fan can be a suitably sized plug fan or a Double Width, Double Inlet (DWDI) fan. A DWDI fan is the most commonly used. The gas burner is mounted in the side of the burner box, upstream from the fan and the fan discharges into the oven transition and into the supply duct. The burner box can be mounted on top, on the side, on the end, or under the oven. The position of the discharge duct and the return air opening should consider the conveyor path and avoid disturbing uncured powder or swinging the parts on the racks. Air flow and temperatures in the cure zone must be designed with the understanding that parts will travel through the oven. These parts must not be disturbed during the cure process and the temperature must be uni-

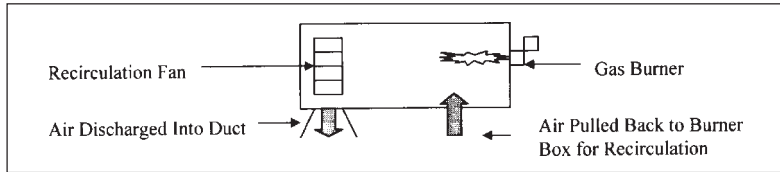


Figure 5-3 – Recirculating Burner Box

form and consistent. Ovens should be specified to provide a maximum temperature variance of no greater than 15 °F (-9.4 °C) from the set point in the cure zone.

Electricity

An oven can function quite well with electricity and the design is very similar to the gas burner box. The electric heating elements take the place of the gas burner in a package type heater with a built in centrifugal recirculating fan. Electric ovens will take longer to bring up to temperature and to cool off, and they are at least 3:1 more expensive to operate than gas. No by-products of combustion are generated with electricity.

Steam

Like gas and electric, a steam heating system is a recirculating convection type. The return air should be filtered with high efficiency air filters to prevent clogging of the steam heat exchanger. The steam heat exchanger should be used with a self-operating regulator with an indicator. The regulator should have a strain for valve protection. A bypass line should be installed for proper heat control as well as a throttling valve self-acting steam control valve. Steam is typically not practical for curing powder coating unless a facility already has a boiler with excess capacity.

3 Infrared Curing

Infrared curing applies light energy to the part surface by direct transmission from an emitter. Some of the energy emitted will be reflected off the surface, some is absorbed into the polymer and some is transmitted into the substrate. This direct transfer of energy creates an immediate reaction in the polymer and crosslinking begins quickly once the surface is exposed to the emitter.

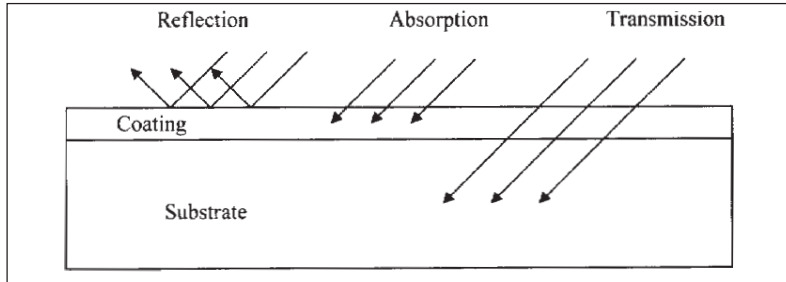


Figure 5-4 - Infrared Behavior

Although IR ovens can cure a coating much faster than convection, differences in the part structure and mass will affect the results. Light energy is dependent on a precise and consistent relationship to the product for even distribution of energy and uniform curing. Areas of a part that are obscured from the emitter by their geometry will not heat up at the same pace as areas that are flush to the emitter. The distance of the part surface to the emitter will also have a profound influence on the curing of the coating.

For these reasons, IR is seldom ideal as a 100% cure option for powder coating but it can be very useful when used with convection to accelerate the cure. Ovens that use some IR in combination with convection can provide some of the benefits of both technologies.

There are certain situations where IR is the best cure method. When the part is very heavy and consistent in shape, IR emitters can be arranged in a pattern that can raise the surface temperature much faster than convection and cure in much less time. IR may be the only practical way to cure certain types of parts by providing a much shorter cycle time.

For systems that run only one product IR can work very well. This is especially true of parts with even surfaces that can be run through the oven with a consistent relationship to the emitter.

In cases where a variety of product with different shapes and masses is coated, IR alone will require frequent adjustments to the position and intensity of the emitters. Powder cure ovens are usually all or part convection type to provide the necessary flexibility for part size, mass and shape.

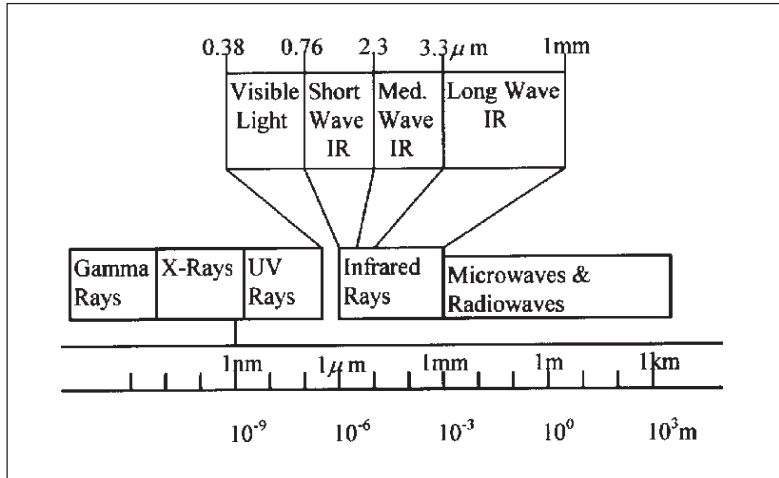


Figure 5-5 - Electromagnetic Spectrum

Infrared energy is a form of electromagnetic radiation, located on the electromagnetic spectrum between visible light and microwaves and measured in microns.

The three wave lengths of infrared, low, medium and high, will emit energy that will be absorbed by the organic coating, reflected from the surface, or transmitted into the substrate.

The actual behavior of IR energy depends on the wavelength, the distance between the substrate and the emitter, the mass of the part and the surface area. The surface of a part with a low mass/high surface area will heat up very quickly when exposed to IR, while a part with a lot of mass and not much surface area will react more slowly.

Short wave IR provides high electromagnetic energy levels. This intense band of electromagnetic energy does not provide much flexibility in the cure cycle. Long wave IR has low electromagnetic energy levels, providing less surface heating than short wave or medium wave.

The most efficient use of IR energy is absorption by the coating. Higher absorption rates are usually found in the medium wavelength, 2.3 to 3.3 microns. Typically, testing should be done to determine the best setting, measured in microns on the electromagnetic scale.

A radiant preheat zone at the entrance end of the cure oven can be an excellent enhancement. Curing will begin immediately and can be accomplished faster than convection heating alone. Radiant cure can be energy efficient if properly designed because it does not waste Btu's to heat the entire substrate or the surrounding air.

In most cases where there is a lot of product variety, curing with radiant emitters alone is not practical. The variety of shapes and sizes require convection heating to ensure that all areas reach the cure window temperature and no area is overheated.

High purity (quartz lamp emitter) IR ovens are very effective for this purpose and the bring up, or response time, is instant. The emitters can be arranged in zones for different part geometries. Turning on different numbers of emitters within a zone can vary the energy levels. The zone control can be turned on by a remote controller or operated manually.

Gas fired radiant emitters work very well also. Like quartz lamps, they can be purchased in modular sections, they can be zoned, and they have a fast response time. The Btu's required to operate a gas-fired IR emitter will typically cost less than the kilowatt-hours required for electric infrared emitters.

Infrared preheat zones for powder cure ovens are typically around 30 to 60 seconds. For exact process requirements, testing must be performed.

4 Oven Heat Containment

It is recommended that all ovens have some method to reduce heat spillage (rollout). The best containment is by use of bottom entry/exit on an elevated or roof mount oven.

On all ovens with horizontal entry/exits there are two (2) options:

1. Powered Air Curtains.
2. Heat relief hoods with a gravity stack and manual adjustable damper.

Powered air curtains will help to reduce the heat rollout from the oven and make it easier to achieve a temperature balance in the oven. They also help to reduce the energy losses that occur as air is heated and expands.

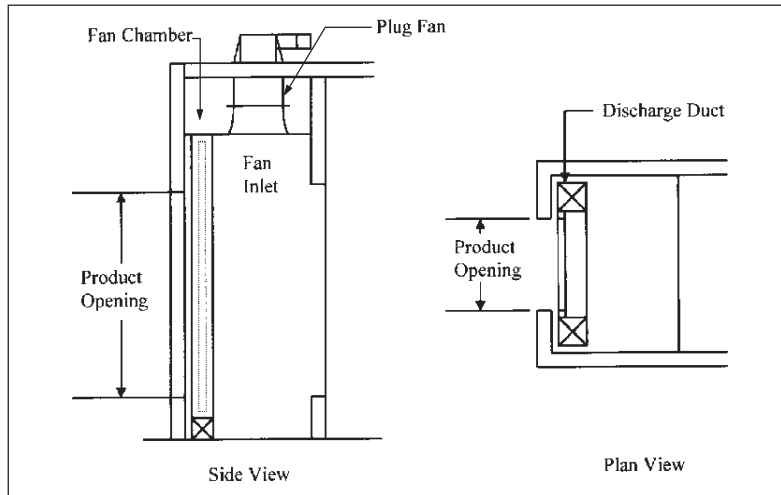


Figure 5-6 - Powder Air Curtain

Heat relief hoods reduce heat build up in the general area and are the recommended minimum for any oven installation.

Powered Air Curtains

The conveyor entrance and exit should be furnished with high velocity air to minimize the amount of heated air in the oven escaping to the surrounding atmosphere, and to ensure the optimum efficient operation of the oven. Each air curtain should be equipped with a fan assembly, complete with shaft, bearings, sheaves, belts, and motor. The air curtain utilizes oven air and does not induce an additional fresh air load on the surrounding area. The discharge velocity should be around 2,000 to 3,000 FPM.

Heat Relief Hood

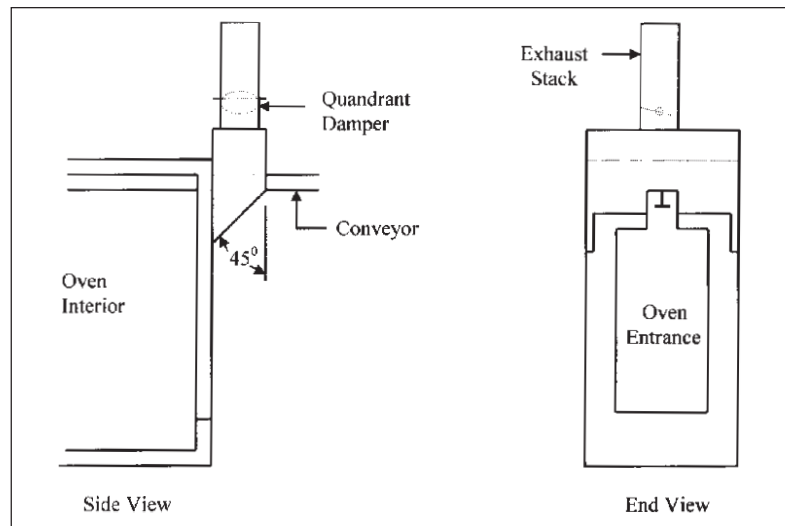
The conveyor entrance and exit can be furnished with a canopy-type heat-relief hood to capture the majority of the heat spillage from the product opening and disperse it to the outside atmosphere. The hood should be constructed of galvanized steel and be designed to be oven supported, with a manually adjustable quadrant damper in a 24" joint of stack. The entrance of a powder cure oven should have a heat relief hood rather than an air curtain so that the uncured powder is not

disturbed. In order for the air curtain to be effective, the discharge velocity should be very high. If the air velocity is reduced to a point slow enough to avoid disturbing the powder on the part, it will not be sufficient for heat containment.

There is some concern about the energy losses that occur if the oven does not have an air curtain. A careful review of the facts shows that this should not be a concern.

The amount of energy loss around a product opening is typically around 50,000 Btu's per square foot. At a typical cost in North America of 0.40/therm, the losses around a product opening of 2' wide x 5' high (0.6 x 1.5 meters) would be \$4.00/hour. An air curtain will be around 70% efficient at best. So the same product opening would lose around \$1.20/hour with an air curtain. The difference in gas consumption is \$2.80/hour. Consider that the air curtain will cost several thousand dollars more than the heat relief hood and that it requires a motor of 10 or 15 horsepower. With the electricity needs of the air curtain and the need to recover several thousands dollars of additional investment the gas losses with a heat relief hood do not appear to be a very important issue.

Figure 5-7 – Heat Relief Hood



5 General Oven Design & Operation

There are some general rules that govern standard good practice in the design and operation of process ovens. Observation of these rules will help a powder coater acquire and maintain a dependable oven.

Oven Cleaning

Oven maintenance is a critical issue in the design. It will be necessary to clean the inside of the oven, so you must have accessibility to the duct, inside and outside and the surfaces should be smooth so that they can be washed or vacuumed. Oven interiors should be cleaned once a week to prevent an accumulation of dirt from building up.

Safety

Explosion relief panels should approach a vent ratio of 1 square foot for every 15 cubic feet of oven volume. They should be installed in the oven roof or similar non-personnel area.

Oven burners are equipped with safety devices to prevent any problem associated with the gas. These safety devices should be tested twice a year to be sure that they are in proper working condition.

Oven exhaust must be suitably sized to remove the gases that are a natural by-product of the cure process.

Training, Maintenance, and Inspection

Train operators in the proper operation of the oven or dryer, and in the specific functions of the various safety controls. Operating instructions should be posted or kept available for ready reference.

Automatic safety controls furnish only partial protection against fire and explosion. The operators must carry out the vital precautions.

Maintain all equipment in good condition.

Safety controls require regular maintenance in accordance with the manufacturer's instructions, and should be inspected and tested periodically. Failure to do this may result not only in fire or explosion damage and personnel injury, but contribute to accidental shutdowns and loss of production.

Shutoff valves, interlocks, and other safety controls may malfunction without the operator's knowledge, unless the faulty controls cause nuisance shutdowns. Operators concerned with production may even bypass a faulty safety control without reporting the trouble.

Inspect and test safety controls periodically. Personnel who are familiar with the equipment and specific functions of the various controls should make the tests. It is usually better to have maintenance personnel rather than the regular oven operators, make inspections and tests.

Suggested Inspection Schedule

Weekly:

1. Flame failure detection system.
2. Ignitor and burner operation.
3. Combustible gas analysis and automatic interlocks.

Monthly:

1. Fuel safety shutoff valve(s) for leakage.
2. Fan and airflow interlocks.
3. Time delay switches.
4. Conveyor interlocks.
5. High temperature limit switch.
6. Door and damper limit switches.
7. Explosion venting latches.
8. For oil: (a) Fuel pressure and temperature interlocks.
(b) Atomizing media interlocks.
For gas: (a) Gas cleaner and drip leg.
(b) High and low fuel pressure interlocks.

Semiannually or annually, (as required):

1. Ignition and burner components.
2. Combustion air supply system.
3. Flame failure system components.
4. Piping, wiring, and connections of all interlocks and shutoff valves.
5. Combustion control system.
6. Calibration of indication and recording instruments.

7. Automatic fire checks.
8. Operating sequence tests, all components.

Purge

A purge of four times the oven volume is required for any oven prior to firing the burner. Since the purge cycle is typically around 30 minutes, it may be desirable to add a second exhaust to purge the oven at a much faster rate. If start up requires a short purge cycle, this should be part of the design. The recirculation fan can be used to accelerate the purge by switching a damper and dumping the fan air to atmosphere instead of into the oven. When the purge cycle is complete, the damper is switched back to recirculation.

Mounting an Oven

Ovens can be mounted on the floor, on a raised platform within the building, or on the rooftop. Where to mount it is a balance of economics and space considerations.

A floor-mounted oven does not require a severe change in elevation, it is easy to service and it is the least expensive way to install. An oven mounted on an elevated platform within the building saves floor space and it may be high enough to provide a bottom entry/exit to the oven. The floor space can be used for storage of product or other items. The bottom entry will provide excellent heat containment.

A roof mounted oven removes the process heat from the building provides a bottom entry and saves floor space. An elevated oven can cost considerably more than a floor mounted oven due to higher installation costs.

Return Air Filtration

Ovens are a source of dirt that can wind up on the product. Vacuuming the oven interior weekly will help to prevent contamination in the oven from building up and becoming a problem.

Another way to help avoid an oven dirt problem is return air filtration. A filter framework is built into the return air opening of the burner box. A row of 30% efficient filters acts as the first layer with a secondary layer of 90% plus efficient filters. This prevents the blower from circulating dirt onto the parts and maintains a constant sweeping action.

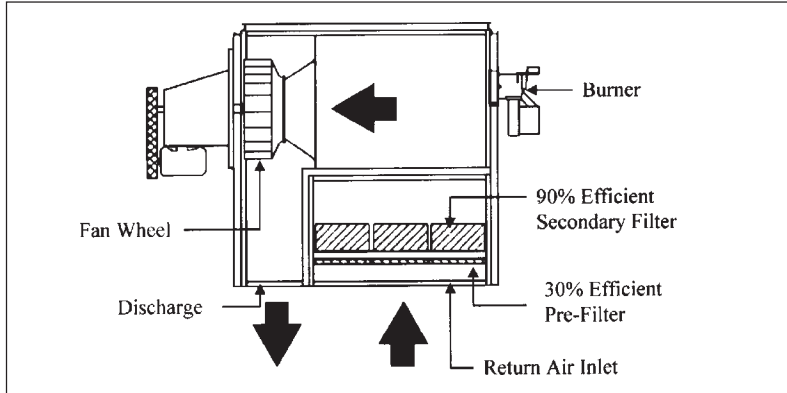


Figure 5-8 - Return Air Filtration

6 Summary

A properly designed oven will have easy access and maintenance features such as platforms, ladders, access doors, lights etc. Make sure your oven will be simple to service so that there is nothing to discourage proper maintenance.

Never make an oven too small; a longer process time can be controlled by less temperature but if the oven is too short it may be a problem, particularly if production increases necessitate an increase in line speed.

The temperature in the work package should be consistent and calibrated to reflect the set temperature at the controller. If the temperature rises and falls during the cure cycle, or if it is inconsistent from top to bottom, the coating may have inconsistent color or gloss. For example, if the top of the oven is significantly hotter than the bottom, the gloss may be higher at the bottom of the rack.

Cold and hot spots can occur along the oven cure cycle if the oven is not properly balanced. Oven balance is accomplished by adjustment of the air volume and velocity at the discharge cones. If the oven is balanced, the temperature in the cure cycle will remain within 10 °F (-12 °C) of the set point.

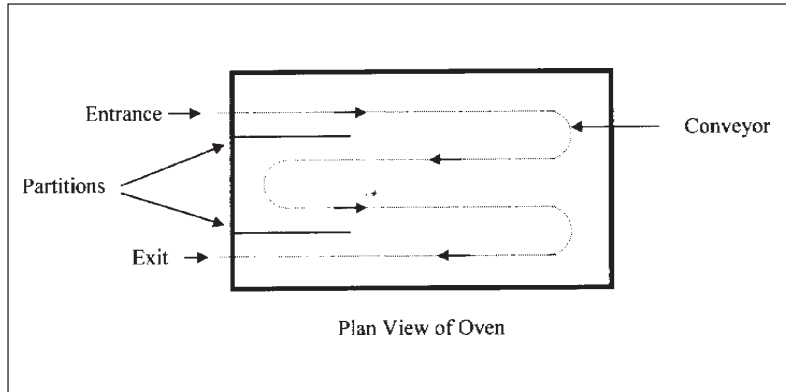


Figure 5-9 - Oven Partitions

Multiple pass ovens are common in powder coating systems. If the entrance and exit are at the same end, a temperature loss can occur when the conveyor passes near the openings. To avoid this loss, partitions should be built to separate the 180° turns from the openings as shown below.

Acceptance criteria for a powder cure oven should include a requirement for a range of control for the temperature throughout the cure cycle.

Occasionally, a light colored powder will yellow in the oven. This is the result of excessive temperature stress or a fouled oven environment.

To be sure that the time and temperature are accurate for the powder, a temperature-recording device should be run through the oven around once a month. The recorder will show how long it takes to get the substrate to temperature and how long it is held at temperature. It will also show any hot or cold spots in the oven.

Fouling of the oven occurs when the exhaust level is too low. Check to make sure that the cubic feet a minute of exhaust (CFM) is accurate for the amount of powder being introduced into the oven. Sometimes a production increase will create more powder throughput and create

oven fouling. Check the formula provided in the cost analysis section of this Manual to determine if your exhaust volume is correct.

The rules for controlling the cure of powder are:

- require that the oven maintain a temperature within 10 °F (-12 °C) of the set point throughout the cure cycle
- measure the temperature frequently for process control
- keep the oven clean; vacuum and wipe down once a week
- measure color and gloss frequently
- have the oven burner box serviced with a planned maintenance visit every six months by a qualified service company.

All powder coating systems require some method of moving the part from one location to another. Parts must be properly positioned for each part of the process. In the washer, parts must be held firmly so that they will not fall off and they must be positioned for good drainage. In the application area the part needs to be hung in a good position for coating that provides good access to the important surfaces. Good rack design and stable movement of the parts is important to overall quality and productivity.

Batch operations usually use a cart with some hooks or racks to hold parts. Some batch operations use a hand-push type conveyor system. Batch systems can be used for any size of part. They are usually designed for low volume production situations.

Automated systems use hooks or racks suspended from a conveyor. Automatic conveyor systems come in a variety of sizes with different features. A powered conveyor allows the system to produce a lot of volume at a consistent pace.

1 Batch Carts

Carts used for batch powder systems should have be sized to define the maximum work area within the oven. The width, depth, and height of the cart are the effective work area inside the oven that can be filled with product.

The cart should have two stationary wheels and two that pivot. The stationary wheels lead the cart into the oven along a guide track; the pivoting wheels allow the cart to be maneuvered into the guide track. The guide track has stops at the back of the oven so that the cart stops in the same position every time. The wheels should be steel or similar high-temperature materials.

For flexibility, the cart can be designed with removable hanging bars so that parts can be loaded efficiently. For tall parts, some of the hanging bars are removed to allow them to hang freely. For parts that do not take up much space, the extra hanging bars can be put in place and allow more dense vertical racking.

In a batch operation, parts will be coated and then moved to the oven by hand. The design of the hooks, racks and carts should consider the

VI

Racking

need to avoid excessive swinging. If the parts touch each other when they are moved or in the oven they will have a surface defect.

A minimum of three carts is needed; one for parts being coated, one in the oven, and one with parts that are cooling.

2 Racking

The first determination that must be made when designing a powder rack is the best position of the part for drainage in the washer and for good powder application. For proper drainage, the part should have all holes, pockets or shelves on a downward angle whenever possible. Sometimes it is necessary to make a change in the manufacturing process to add holes for drainage.

For proper coating, the "A" surfaces of the part should be presented to the guns as squarely as possible.

The most important part of the rack is the clip or contact point. There are times when universal racks with simple hooks will work well. But many times, a specially designed clip will offer four advantages.

1. The part can be held rigidly so it will stay on the rack better in the wash and the powder booth.
2. The clip will touch the part in the same location every time, keeping it free of powder and improving ground.
3. The parts can be positioned firmly for efficient racking with better yield and minimum open space.
4. Parts can be grouped in a pattern that provides the best possible rack density.

Good contact must be maintained between the part and an earth ground to ensure that charged particles are attracted to the target part and not to a more prominent ground. **Efficient ground is measured as less than one megohm of resistance between the part and ground.** If the parts are not properly grounded airflow and gravity can overcome the electrostatic attraction and prevent the particle from reaching the part. Also, the powder particle does not have a brain; it will go to any good ground such as the booth wall, the conveyor, the gun barrel or the arm of the operator.

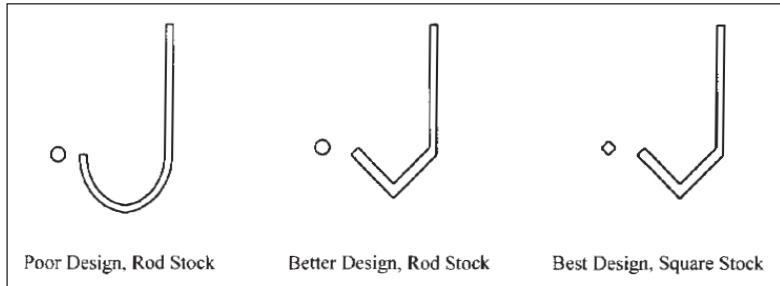


Figure 6-1 - Hook Design

Grounding problems are usually due to poor rack design and/or maintenance.

Contact points should be firm and consistent, and, if possible, "hidden" from the powder spray. Round wire hooks with radius bends are the least desirable type of contact for powder. A square stock that is formed on-edge to provide a sharp point for contact will work better than the radius of a rod stock. If hooks are the only way to hold the part, the bend should be as sharp as possible.

This will assist the ground process by keeping the part in the same location all the time. All hanging points and contacts must be free of powder to ensure proper ground.

Strip the contacts frequently and use a minimum of hanging attachments. Keep in mind that a set of tooling for a particular part may be cheap when compared to losses related to poor ground.

Some parts are best hung from stainless steel spring clips. A piece of stainless spring stock can be formed in different shapes with different kinds tips and used to hold a part firmly by applying tension to the part.

3 Types of Conveyor

Conveyorized powder coating systems are designed for higher volume operations. Belt conveyor, chain-on-edge conveyor and overhead conveyor are used in powder coating systems.

The simplest overhead conveyor is a hand-push trolley system. It has load bars attached to trolleys that ride in a box-shaped track or on a beam. Load bar assemblies can be designed to hold loads of anywhere from 250 pounds to 4,000 pounds. Movement of the parts suspended from the trolley assembly is accomplished by an operator who pushes the trolley along the track. Usually, these systems do not have any elevation changes. Switches can be used to route the load bar through one of several powder booths or other discreet stations within the system. The switches, which look and act like railroad switches, are activated by the operator who pulls a cord to move the part onto the appropriate track. Parts stand motionless inside each station of the operation. These systems can provide excellent flexibility for the low-volume coater.

Powder coating on blank sheets is done with a belt conveyor. The blank sheet of steel is laid flat on a belt conveyor and moved at very high speed under a row of fixed guns. It is then conveyed into an infrared oven for curing. The blank sheet of steel is used for appliances or similar products that can be fabricated from pre-coated stock.

A chain-on-edge conveyor supports the part on a spindle above the conveyor chain. The chain is sometimes a rivetless-overhead chain or a roller chain that is run on its side. The chain pitch is typically 2 to 3" and loads are limited to around 25 pounds. Chain-on-edge systems are used for situations where a single part, or small family of similar parts, can be run through a fixed gun arrangement, with rotation to access the entire part surface. Chain-on-edge systems are also run at high speed and parts are cured with infrared ovens. Oil filter canisters or similar parts with uniform shapes work very well in these systems, producing parts at a very fast pace.

The most common type of conveyors for powder coating is the continuous speed, overhead system. These systems use a conveyor drive to power the product through the system with a fixed or adjustable line speed.

Enclosed track and I-beam type conveyors are commonly used for powder systems. The enclosed track works well for lighter duty situations. When a more heavy-duty chain is required the overhead conveyor will be an I-beam. I-beam conveyor comes in different sizes ranging from 3" to 6".

Selection depends mostly on the product size and weight. Each conveyor has a limit of weight that can be hung on each hanger point and a different chain pitch between available centers.

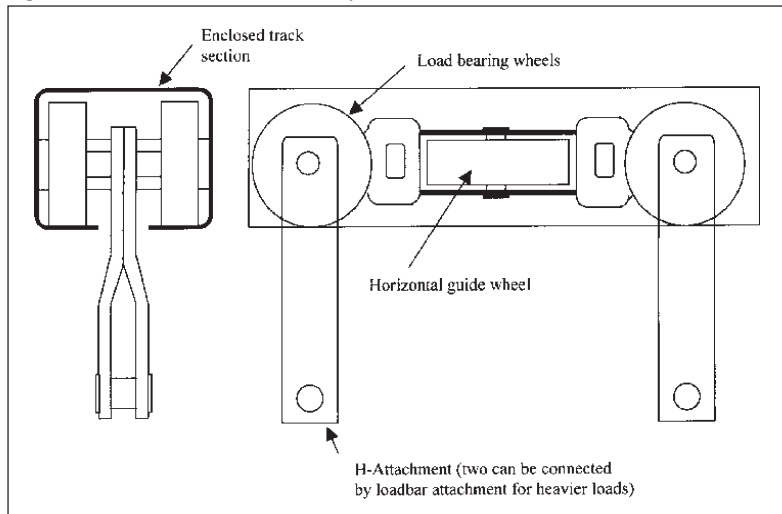
- Enclosed track – 80 lbs.
- 3" I Beam – 250 lbs.
- 4" I Beam – 500 lbs.
- 6" I Beam – 1,200 lbs.

Enclosed Track Conveyor

The enclosed track conveyor uses a box-shaped section of track with a slot in the bottom. The chain has vertical trolleys to support the work in process and horizontal wheels to maneuver the chain through the horizontal turns. The typical standard pitch distance between hanger centers on enclosed track conveyor is 8 1/8". Hanging attachments can be installed at each available site or any increment of 8 1/8." Two hook sites can be connected by a loadbar attachment to double the capacity of the hanger.

Enclosed track conveyor is generally lower in cost than I-beam since the track components are standard sizes that are usually readily avail-

Figure 6-2 - Enclosed Track Conveyor



able from stock. Rollers or traction wheels are not required for turns because the chain rides inside the track. Horizontal turns can have a tighter radius than I-beam systems, which can be an advantage in the sizing of the equipment and overall layout.

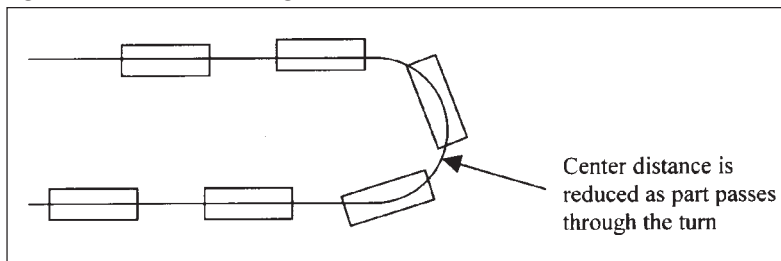
I-Beam Conveyor

In an I-beam system, the trolleys ride on the lower flange of the beam. The rivetless chain is suspended from the trolley attachments below the beam. A variety of attachments can be bolted to the end of the trolley attachment. Like the enclosed track conveyor, attachments can be joined by a load bar to increase the capacity per hook site. The larger the size of the I-beam, the more weight the conveyor will support.

Horizontal turns in I-beam systems are supported by rollers or traction wheels to maintain tension on the chain and guide it through the turn. The turn radius is limited to a minimum of a 2' radius. Turns should be carefully sized to make sure that parts will not hit each other or come in contact with any surrounding equipment or building steel. The center distance is reduced as the part passes through the turn. To size the turns, an analysis of the conveyor part-path is performed with the largest part, racked on typical production hanging centers. The turn radius must be big enough to allow for the swing-out of the part as it passes through the turn.

Changes of elevation need to be studied also, to make sure that parts have adequate clearance in the incline. A sharp degree of incline may force the operator to hang parts farther apart. A good starting point is 15° from the horizontal. Inclines with a sharper angle should be checked to make sure that parts will clear.

Figure 6-3 - Part Path through a Horizontal Turn



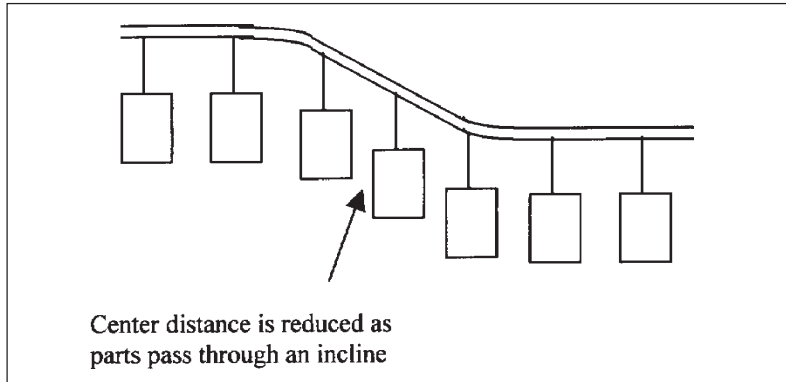


Figure 6-4 – Conveyor Inclines

Controls for Continuous Speed Conveyor

Most of the time the controller for a continuous speed system will use relay logic. An electrical variable speed controller with a digital read out in feet per minute should be used. This will provide good process control and the opportunity to vary speed for different products, materials or changes in production volume. The controls should include a start-up warning signal, emergency stop capabilities and overload shut-down protection. The conveyor drive will be fitted with a shear-pin to stop the conveyor in the event of a jam. For a more sensitive and faster response, a limit switch can be installed on the take-up. The limit switch will sense any unusual tension on the chain and stop the drive.

Lubrication

For smooth operation and low maintenance, an automatic lubricator is used to maintain the trolleys, chain and drive. Lubrication is required on all of the moving components including the chain pins, wheel bearings and drive chain. Lubrication is essential on conveyor systems that must pass through ovens and a washer.

The lubricator should provide a thin lube, penetrating lubricant, operating on a programmed basis using photo eyes to recognize the points to be lubricated. Common lubricants for conveyor use molybdenum disulfide other moly-type material. This will ensure continued good lubrication without contamination. Lubricators that drip heavy oil are

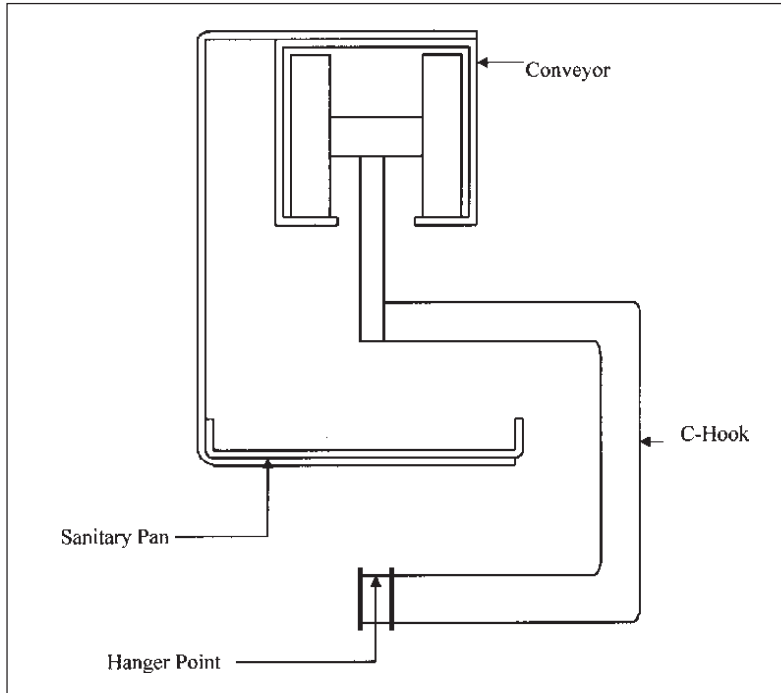


Figure 6-5 – Sanitary Pan

not recommended because they can contaminate work in progress. Proper lubrication will extend the life of the conveyor indefinitely.

Sanitary Pan

If dirt is a concern, as it is on almost all paint systems, a sanitary pan should be installed under the conveyor to protect the parts from dirt falling off of the chain, hooks and track. The sanitary pan is a light-gauge metal trough that hangs under the conveyor. A C-hook is used to fit around the pan for attachment of hanging fixtures.

Inverted Box Track

This type of conveyor uses a conventional box track mounted in an inverted position. The chain has vertical and horizontal trolleys that provide stability for the H-attachment. A c-hook is used to reach un-

der the track for attachment of hanging fixtures. A rigid H-attachment is used to keep the hook stable. The slot of the conveyor is pointed up so that conveyor contamination cannot fall onto parts. This arrangement is a very clean system and it does not require a sanitary pan. This arrangement requires a long C-hook that may bend if too much weight is hung from the hook.

The conveyor drive will normally engage the chain from the top. When the track is inverted, the cat-drive will engage from the bottom. This will require a very long C-hook to reach around under the drive. To avoid an excessively long hook, the drive should be designed as a gear-type that engages the chain from the side of the track.

Take-up and Drive

Drives can be either caterpillar chain or sprocket-type. They impart the mechanical force to the chain to move it through the system. Typically, the drive unit is a floating frame type. The motor, reducer and power transmission float in a fixed frame. The drive is located at a point where it can supply significant pulling force on a heavily loaded portion of the chain. The drive is usually not located too close to an oven entrance that could dry out the lubricant and somewhere before the washer so that parts are not contaminated by drips.

The function of the take-up is to maintain tension on the chain. It can be adjusted to compensate for chain stretch. As the chain stretches, the amount of slack may become too great to be "taken up," and it will become necessary to remove links from the chain. This is a part of regular chain maintenance.

A spring or counterweighted take-up can be used but a pneumatic take-up is preferred for thermal expansion and contraction. The cat drive should be located just before the take-up. Avoid excessive pressure on the pneumatic take-up. It should be no greater than 10 PSI to avoid binding the chain.

Power and Free Conveyor

A power-and-free system utilizes a free rail and multiple drive rails to transport parts through the various stages of the process at different speeds. The drive rail, which has a chain and drive like the continuous speed conveyor systems, sits above the free rail. Two load supporting

VI

trolleys, connected by a load bar, ride on the free rail below. The power track chain engages the trolleys and moves the load to a predetermined location. The load can be dropped and picked up by another drive. This gives the power-and-free conveyor the flexibility to move product at different speeds, to stop and accumulate product on load bars, or to route product to different locations.

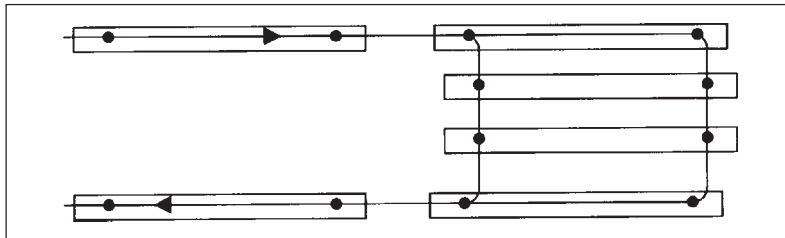
In powder coating systems, it can be used to route parts to any number of booths, each dedicated to a single color. It can also be used to bank parts in the oven, on close centers and hold them for a period of time, thus reducing the oven size.

One of the reasons that a powder coater would consider a power-and-free system is very long parts. Parts in excess of 20' can be very difficult to turn. With a power-and-free system, the two trolleys can be moved onto separate rails to make it possible to reverse the direction of the part without a turn.

The flexibility of a power-and-free system can make them a very desirable asset in certain situations. However, power-and-free systems are complex designs that must be carefully balanced to avoid problems. They are also very expensive and they require more conscientious maintenance and care in operation.

Controls for power-and-free systems utilize programmable logic controllers (PLC) for operation. The carriers are fitted with coded identification methods to indicate to the PLC how they are to be routed through the system. A mechanical flag or bar code is used to identify each carrier. The loader inputs the process information related to the carrier. As the carrier approaches a switch point, the flag is read by a photoeye and the PLC determines which way to route the carrier.

Figure 6-6 - 180° Turn with Power-and-free Conveyor



| Conveyor | Weight Limit per Hook | Nominal Hook Centers |
|----------------------|------------------------------|-----------------------------|
| Enclosed Track | 80 lbs. | 8 1/8" |
| 3" Beam w/x348 Chain | 250 lbs. | 6" |
| 4" Beam w/x458 Chain | 500 lbs. | 8" |
| 6" Beam w/x658 Chain | 1,200 lbs. | 12" |

Table 6-1 – Conveyor Capacity

The operator may interface with the control system with simple indicating lights or a more sophisticated system like a touch screen or other graphical system.

The controls for any conveyor system should include a simple to understand input process to avoid operator error. Audible alarms should be included to announce a start up of the drive. System status can be monitored and details of daily operation can be stored and retrieved. Careful thought should be given to what control features are needed.

Testing is performed on the finished film to confirm that it has all of the performance properties that the material is supposed to provide. Testing confirms that the pretreatment process is working correctly, providing the necessary properties to the substrate prior to coating application. Testing also confirms that the powder has been properly applied and cured. Initial testing of a coating process is used to establish a standard. Periodic testing is done to confirm that the process is able to maintain the standard.

Panels for coating tests are run through the washer and then coated the same as production parts. The panels are usually aged for 24 hours at room temperature prior to testing.

Test methods must be standardized in order to provide a common method of communication and accurate measurement of the coating. There are organizations that produce standard test methods for coatings analysis. They establish guidelines for what the test means, how it is done, what is used for the test, and how the results are measured and recorded. There are national organizations such as the American Society for Testing and Materials (ASTM) and the German Industrial Standards (DIN). There are also international organizations such as the International Standardization Organization (ISO). Trade associations, such as the Powder Coating Institute (PCI), sometimes publish recommended test procedures. The important thing is that a seller and a buyer agree to a standard method of confirming the finished coating.

1 Color & Gloss Measurement

The precise match of color and gloss can be a very critical part of the operation. Matching color and gloss requires consistent material from the supplier. Incoming batches of powder should be tested to confirm that the color and gloss are correct. Consistent operation of the powder system is also important. Differences in the film thickness or cure cycle may have an impact on color and gloss.

Color can be tested by visual inspection or computerized methods. Visual inspection is useful for spot checking and comparing a part to a visual sample. To confirm visual results and for greater accuracy a color measurement device is used.

For color, a colorimeter is the most common device used to measure color. A colorimeter produces a measurement in three numbers called tristimulus values. The values are the amount of primary colors in the coating — red (X), green (Y), and blue (Z). Each color has its own tristimulus values that distinguish it from any other color. These values can be measured to determine if a color match is accurate. They can also be used to determine the direction and amount of any color difference.

In many cases the XYZ values of a coating are converted to the Hunter L, a, b scale. The "L" is for lightness, the "a" is for redness-greenness, and the "b" is for yellowish-bluish. Numbers for the L, a, b scale are established for a given color and a numerical tolerance is established. A typical tolerance might be $\pm .5$. For example, a measurement of $-.5$ on the L axis would indicate that the color is .5 points too light. More stringent tolerance might be required in some industries. However, the human eye cannot detect slight color differences so some tolerance is acceptable.

To be sure of correct color matching from batch to batch, start out with a practical tolerance that satisfies the needs of the product and is reproducible by the coating manufacturer. Check for any differences between your colorimeter and the one used by the coating supplier. Measurement will vary from one device to another, even if they are made by the same manufacturer. Keep the color measurement device accurately calibrated. Keep a master sample of a color and make visual matches to the master panel.

Have the powder supplier include a sample panel from each batch of powder or spray a sample before putting the material into production. Take a color measurement from the sample to verify that the color is accurate. This will ensure that a poor color-matched batch of powder is never used on production parts.

Remember that a color may look different in different lighting and at different angles. As a result, two samples may match under one set of viewing conditions but not match in another. This phenomenon, called metamerism, can cause an operator to make a mistake if they rely on one visual inspection without varying the light source, viewing distance, or angle of the part. Visual testing of panels is usually done in a

controlled space such as a light booth. The light booth uses different light sources to visually evaluate color differences. The International Commission on Illumination (ICI) has standardized on North Daylight as illuminant D65 and Incandescent as illuminant A. Cool White Fluorescent is the third light source and it has not been standardized by ICI.

The texture and gloss of the panel can also cause a false reading. The gloss should be checked with a glossmeter and the texture should be visually inspected.

The basic unit of color measurement is a Just Noticeable Difference (JND). A difference of one JND is a very close match. Beyond one JND begins to be noticeable to the human eye. Color difference equations calculate the difference between a desired sample and a test part in units of E. The color difference is referred to as the delta E.

Color Glossary

1. Appearance – the way an object looks; the color, gloss and texture.
2. Color – visual response to light consisting of hue, saturation, and lightness.
3. Color Difference – magnitude and character of the difference between two colors.
4. Color Tolerance – limit of color difference from a standard which is acceptable.
5. CIE LAB of $L^*a^*b^*$ E – the color difference based upon the 1976 CIE color difference equation. On CIE LAB E is approximately 2 JND units of color.
 - ΔL – designates lightness difference
 - Δa – designates redness-greenness
 - Δb – designates yellowness-blueness
 - ΔE – a unit of color difference. It is the total difference in hue, saturation, lightness
6. FMC 2 E – color difference based on the Friele, MacAdam, Chickering Color difference equation. One FMC 2 E is approximately equal to one JND of color difference.

7. Gloss – subjective term used to describe the relative amount and nature of mirror-like reflection. Different types of gloss are frequently arbitrarily differentiated, such as sheen, distinctness-of-image gloss, etc. Trade practice recognizes the following stages, in increasing order on gloss:
 - Flat or matte – practically free of sheen, less than 15 on an 85° meter.
 - Eggshell – usually 20-35 on a 60° meter.
 - Semi-gloss – usually 35-70 on 60° meter.
 - Full-gloss – smooth and almost mirror-like surface when viewed from all angles; usually above 70 on a 60° meter.
8. Geometric Metamerism – phenomenon exhibited by a pair of colors that appear to be a color match at one angle of illumination and viewing but that no longer match when the angle of illumination or viewing is changed; caused by gloss and/or texture differences.
9. Hue – color variable denoted by red, orange, yellow, green, blue, and purple.
10. HUNTER Lab E – the color difference based on Hunter's color difference equation. One Hunter Lab E is approximately 3 JND units of color.
11. Lightness – color variable denoted by neutral gray scale from white to black.
12. Metamerism – when two or more samples match under one set of viewing conditions but do not match under a different set of viewing conditions for the same person.
13. Saturation – color variable denoted by purity or departure from grayness.

For measurement of gloss, a glossmeter is used. Gloss is a measurement of the amount of light that is reflected to a viewer's eye. The light reflected is converted to an electronic signal by a phototube. The strength of the signal is related to the amount of light reflected. The reflected light is compared to the original light falling on the surface to measure the gloss. The angle of reflection may be 20, 45, 60 or 90°. 20 or 60 are the most common angles for gloss measurement.

2 Film Thickness

A film that is too thin may show bare steel through the coating or it may not have the performance properties required of the finished film. A film that is too thick may not have correct color or gloss, it may have too much texture, it may be too thick for a fit to another part or it may be just a waste of money. Film build control is important to help deliver consistent results and avoid these problems. Understanding the application variables and the particular powder material being used can help to control film build and maintain a consistent level of quality.

Film thickness gauges can be used to measure the finished film in mils or microns. This is a valuable tool to monitor the process for efficiency. Some gauges are capable of measuring ferrous and non-ferrous metals. Others are designed for one or the other.

Gauges used for ferrous metals are often magnetic. Magnetic gauges offer quick, accurate, non-destructive measurement on steel surfaces.

Different types of gauges are made for aluminum, copper, zinc, brass and other non-magnetic surfaces. Usually, these type of thickness gauges measure the strength of eddy currents induced in the metal by a probe containing a conducting coil.

A third type of film thickness gauge is the Tooke gauge. A Tooke gauge cuts a small, precise groove in the coating and measures the film thickness from the visible cross section of the coating film. These gauges are less commonly used because they create a surface blemish in the film.

3 Film Hardness

The film hardness will affect its brittleness, its resistance to moisture penetration, its flexibility and resistance to scratching. The desired film hardness relates to the use of the product in the field. Film hardness is measured to confirm proper cure of the material and to monitor product quality.

Hardness is often measured with the pencil hardness test. A specific set of Faber Castell wooden testing pencils is used with leads that have progressively harder tips. The pencil is pushed into the coating at an

VII

Flexibility, Impact Resistance

angle to determine how hard the lead has to be in order to break through to the coating to the metal substrate (ASTM D3363). The hardness is defined by a numerical value equal to the hardest pencil that will not break the surface.

4 Flexibility

The flexibility of the coating can be important if the field use of the part will cause it to be stressed by thermal changes or handling. A conical mandrel bend test is used to test the coating for flexibility and adhesion.

1. The panel is placed between the mandrel and the drawbar.
2. The test panel is folded around the tapered fixture in a uniform 180° bend using a manually operated arm.
3. The panel is inspected for cracks along the bend.
4. If cracks appear, they are measured from the small end of the bend to the far end of the crack.

The amount of crack that is acceptable is determined by the use of the product. If the part will not be subjected to stresses in the field the standard may be several inches. If the part is used for a product that has a post-coating forming step or if it is used in an environment that will subject it to stresses then the standard may be no cracking.

Conical mandrel bend testing is also an indicator of adhesion loss as described later in this chapter.

Another test for flexibility is the Erichsen slow penetration test. The panel is subjected to deformation by a ram. The ram is driven slowly into the back of the panel. Flexibility is measured by how far the ram travels before coating cracks.

5 Impact Resistance

Impact tests can be performed as direct impact or reverse impact. Both tests use a Variable Height Impact Tester. The panel is placed on a surface under a tube. A cylinder of a precise weight is dropped down a tube onto the panel surface from different heights. For direct impact, the coated side of the panel is facing up and the cylinder is dropped onto it. For reverse impact the panel is turned down and the cylinder is dropped onto the non-coated side. The results are reported in inch-pounds, the maximum impact that the coating will take before it cracks.

6 Abrasion Resistance

Abrasion resistance is another mechanical test used to determine how much physical abuse the coating will take. It is usually performed with a Taber Abrader. Panels are rotated under abrasive wheels of a specific hardness at specific weights. The loss of coating is measured in weight.

Another device that is sometimes used for this test is a falling sand abrasion tester. Sand is dropped down a vertical tube onto the panel that is mounted at a 45° angle. The results are given as the amount of sand required to remove a certain thickness of coating.

The operation of a powder coating system is subject to a number of variables that can affect the outcome of the finished parts. Control over these variables can provide a much better level of consistent quality.

1 Definition of Quality

Quality is often defined by subjective judgment. What is acceptable may vary from one day to the next, one shift to the next, one inspector to the next, etc. Quantitative information is necessary to create and administer a proper quality specification. Specific numerical ranges for gloss and color, the numbers and description of any dirt speck that may be acceptable or not acceptable, corrosion resistance, hardness, etc. Anything that relates directly to the appearance or function of the part being coated.

The properties that the coating must have are directly related to the use of the product in the field. Quality is actually defined by the expectations of the most demanding customer. The performance and appearance requirements are dependent on the acceptance of the user. A quality specification that meets the customer's expectations can be priced into the product. A quality standard that exceeds the customer's expectations will add cost to the product, reducing profits. A standard that is below the customer's expectations may not sell at all. A quality control method that is subjective will result in inconsistent output, added cost and customer dissatisfaction. Accuracy is important.

Powder coaters need to recognize the variables that affect the coating process and learn how to manage them. *G. Edward Demings* defined quality as absence of variance. It is true that if a coating line focuses on the reduction of variables that cause defects, they can achieve the highest possible yield of acceptable product.

2 System Design

Quality starts with the design of the powder system. Decisions must be made on features and benefits of the equipment and layout. Certain features must be looked at very carefully from the standpoint of quality output.

- materials of construction – non-corrosive, easy to clean, durable
- sizing – adequate for the task with flexibility for various products & future growth
- space utilization – allowing proper space to accomplish each sequence of the process
- filtration – protect the system components and the air stream from dirt
- air management – control of air volume, direction and velocity
- maintenance accessibility – easy access to all points that need regular service

In addition to good design practices, achieving quality goals may require that decisions about capital expenditure consider long term operating efficiency and cost. Many times, purchasing decisions are focused on the original equipment cost. Buying the proper equipment needed to achieve the necessary level of quality and efficiency requires a more thoughtful approach to capital equipment purchase decisions. The cost must be weighed against the benefit so the purchaser must have an understanding of what equipment features will be necessary to achieve the quality levels expected.

3 Air Management

Air management means control of air volume, velocity, airflow direction, filtration, temperature and humidity. In a facility that includes a powder coating system, air management affects the performance of the equipment, the comfort of the workers, and the system efficiency.

It is a mistake to install a powder system without planning for proper air management. Air volumes and velocities affect the ability of the powder booth to contain overspray and they can affect transfer efficiency. Control of air affects worker comfort and prevents gasses from escaping the oven. Good management of air provides the lowest possible expense for energy. For peak efficiency, it is important to manage the behavior of the air within the plant.

Air management for the powder system is often not given the same consideration as other issues even though it is important to the function of the individual pieces of equipment and the finish quality. Other issues that are a natural part of a manufacturing operation make it difficult for a manager to take the time to learn the details of air management.

All of the equipment in the coating system uses air movement as part of the operation. The system is designed to move air of a certain volume, in a certain direction, at a certain velocity and maintain a certain temperature and humidity.

Air Volume

The volume of air is critical to the performance of the equipment and the overall system. The air volume from exhaust will set up a chain reaction of air movement and create a demand for air supply. For every cubic foot a minute (CFM) of air that is exhausted, one cubic foot per minute will enter the building. Air management means having a deliberate supply of the proper volume of filtered and tempered air instead of allowing it to infiltrate through holes in the building.

In a building that is exhausting air and pulling in make-up air by infiltration a number of problems can occur with the performance of the equipment.

Air Control for the Equipment

Each piece of equipment has a need for air management. Powder booths, ovens, and washers can have problems related to lack of control over airflow.

Powder Booths

Powder booths are designed to provide containment of oversprayed powder. The reclaim system pulls the powder and air mixture to the filter system and collects the powder for reuse. Containment is accomplished by moving air at a specific velocity across the openings of the booth shell (100 to 140 fpm/30 to 43 mpm).

If the air speed into the booth is too fast, it will interfere with transfer efficiency. If it is too slow, overspray may migrate out of the booth and land on the parts in-progress or on other surfaces. Cross-drafts from openings in the building or improperly installed discharge duct can interfere with the booth containment air and pull powder out of the booth. Powder particles that escape the containment system of the booth are dirt particles that will create rejects.

If the building is under negative air pressure there is no control of air direction, volume or velocity. Powder may be allowed to migrate out of the spray booth and into the general atmosphere, creating a messy environment and wasting powder material. Cross-drafts occur and powder is lost from containment.

Also, air that infiltrates through openings in the building carries an excess amount of dirt into the building that may cause coating rejects.

Airflow around the booth needs to be quiet and controlled. The ideal way to control the area around the booth and application area is by enclosing the spray booth in a separate application room and treating the air inside the room independently from the rest of the building.

The air in the room should be supplied through the use of an HVAC, an air handler that provides heating, ventilation and cooling. The HVAC system supplies enough outdoor air to maintain positive pressure in the room with a slight discharge at the product openings (around 0.01" water column).

The HVAC controls the temperature between 60 and 80 °F (15.6 and 26.7 °C) and the humidity between 50 and 70% RH so that

powder fluidization and flow is smooth and consistent. The slight pressurization prevents unwanted cross drafts that might interfere with containment or with transfer efficiency.

The powder room should be big enough to provide space for the booth and all of the reclaim equipment. Operators must be able to move around the booth area without restriction. Clearance is necessary for removal of cartridge modules from the booth for color change. And powder material must be stored with the powder room or in a separate air-conditioned room nearby.

Ovens

Ovens need supply air to avoid excessive heat roll-out and to keep exhaust gases and by-products of combustion from escaping into the building. The oven is usually slightly negative in pressure because of the exhaust. Air will move across the oven opening to make up for exhaust air.

If the air speed in the oven is too fast it can blow parts off the racks or powder off of the parts. If the air is not turned over fast enough through the proper exhaust volume, the oven interior may become saturated with gases and cause discoloration of the parts. The recirculation and the exhaust fan air volume and velocity is important to the function of the oven.

The product opening will have warm air migrating out around the top, due to expansion from heat, and cool air migrating in at the bottom to replenish air that is being exhausted. Air seals designed to contain the heat roll-out should have manifolds with slots that can be independently adjusted at the bottom and the top. This way, it is possible to aim the top slots in towards the oven interior a little and the bottom ones out a little to discourage the natural tendency of the air movement and create a more even air flow. This will reduce the heat roll-out and dirt infiltration.

Powered air curtains at the entrance of powder cure oven can cause uncured powder to be blown off of the parts. A cure oven entrance that is fitted with an infrared booster section or a heat relief hood is preferred to avoid disturbing the uncured powder.

In buildings that have negative air pressure, back-drafts can occur. This can cause the burners to go out or it can trip the oven airflow

switch and turn the oven off. A nuisance shut down in the oven will require a complete start-up cycle with an oven purge. Purge times can be as long as 30 minutes. Pressurization of the building prevents back-drafts.

Washers

The washer needs supply air in order for the exhaust fans to perform their job of vapor containment. If the air speed of the exhaust fan is too fast, it will cause excessive moisture and chemical to be pulled up into the exhaust; too slow, and the vapor may roll out of the opening. Containment velocity for the washer should be between 150 and 200 feet per minute (45 to 61 meters per minute). In a building with negative air pressure it is common to have air movement that creates a wind-tunnel in the washer and carries vapor out of the opening, especially if the washer is in line with a dock door. Pressurization will prevent air from moving in one direction at a high enough velocity to disturb the containment air of the washer.

All of the equipment in the coating system will function best when the environment is controlled. Peak performance of coating materials and the efficient operation of the oven and washer depend on a reasonable and steady temperature.

Consider some of the benefits of properly filtered AMU:

- limited dirt infiltration
- no back-draft down exhaust stacks
- no condensation inside building
- proper air flow for containment of overspray in spray booths
- filtered supply air to all of the process equipment
- no flame-out of gas burners
- no accumulation of gases or smokes in the building
- no loss of water vapor from the washer
- the best possible worker comfort

Proper air management provides an opportunity to control the process. Process control is the tool used to track the operation and control the variables. Control of process variables can lead to the highest possible quality levels and the lowest operating cost. Control of air volume is essential to process control.

Air Velocity

Air velocity is also an important aspect of the process. Air speed will affect the performance of the equipment. Improper air balance may cause air movement in the wrong direction and add a lot of contamination to the coating process. Each piece of equipment is designed with certain air velocity controls. Too much or too little air speed will cause problems with containment of powder in the booths, vapors in the washer and gases in the oven.

Indoor Air Quality

Another issue related to air control is the indoor air quality (IAQ) in a factory environment. The single most important factor that affects the quality of air in a building is the introduction of outdoor air for ventilation. Every building produces contaminants such as exhaust gases, byproducts of processes, dust and oily dirt.

Containment of contaminants is important to product quality. Dilution of contaminants can be accomplished by introduction of outdoor air. Outdoor air is introduced into the building to displace contaminated air. Dilution allows exhaust fans to perform properly and is effective for airborne contaminants that are widely distributed, such as dust and dirt.

Source capture can be used to collect and exhaust localized air contamination such as oven exhaust gases. A properly designed hood or enclosure uses a fan and exhaust stack to power the unwanted byproducts out of the building.

Dilution and source capture are both dependent on management of air into and out of the building. Dilution requires pressurization of the building to be effective. Source capture requires make up air to replace the air that is exhausted. The control of how much air goes out, how much comes in, and how it is moved is the essence of air management.

Exhaust Air

Ovens and washers have several points of exhaust to remove gases that develop from combustion and from the curing process and water vapor from the washer. As previously mentioned, exhaust air creates negative air pressure in the building, causing air to infiltrate through

doors and other openings in the walls. For every cubic foot of air exhausted, one cubic foot of air will infiltrate.

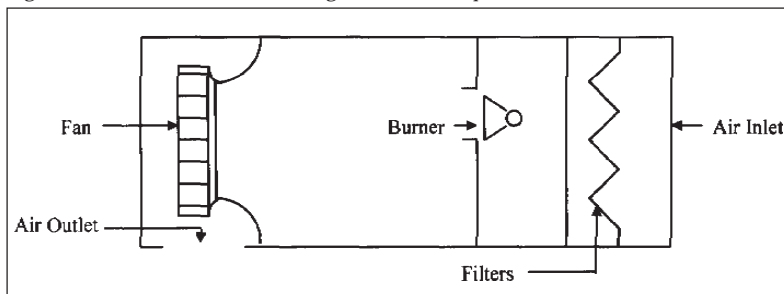
Exhaust fans are designed to exhaust a specific volume in order to provide the proper dilution of air in the ovens and keep the water vapor contained within the washer. The operation of the fan depends on the supply of make-up-air. If the air is not supplied into the building from a controlled source, the air pressure inside the building will be negative. Negative air means that there is pressure from outside the building caused by the mechanical exhaust. Air that is exhausted will pull air into the building through cracks in the walls and around doors and windows. Negative air pressure in the building may starve the fans for air and they may not be able to do their job effectively.

- Cross drafts may occur from dock doors, causing areas of the plant to be very cold while other areas are very hot.
- Back drafts may occur, causing gases to escape from the oven.
- Back drafts can also cause the burner flame to go out.
- The cure oven may not be able to hold even temperature throughout the cure zone.
- The powder booth may not be able to contain the oversprayed powder.

Air-Make-up

There are significant benefits to building pressurization. Pressurization occurs when air is blown into the building through a heater that is designed to supply make-up air. It is similar to blowing up a balloon with holes. The heater provides the air and the environmental control needed for effective operation of the powder system.

Figure 8-1 – Side View of a Straight-Air Make-up Heater



In a building that is pressurized the introduction of air to compensate for exhaust is all through a single controlled point, the building air handling system. All of the air required to make-up for exhausted air and provide building heat or ventilation can be treated for heating, cooling, control of humidity and filtration. It is pushed to outside walls, creating equal pressure and comfortable environmental conditions throughout the building.

In order to pressurize a building, all replacement air for mechanically exhausted air is passed through the air handler along with an additional volume to counter the effect of wind and temperature-induced infiltration.

A building that is under slight positive pressure will fight the natural effects of the wind outside the building and reduce cold air drafts into the facility. At open dock doors a pressurized building will allow a “bubble” of cold air to enter the building, compared to the “river” of cold air that enters a building when air pressure is negative. Pressurization produces a buffer to push heat out towards the walls of the building and reduce the natural effect of outdoor wind and cold.

Pressurization needs vary due to the dynamics of the building. The total air volume may need to be changed as the wind direction and velocity shifts, doors are alternately opened or closed, and fans are cycled on and off. The optimal control strategy can respond to these changes and adjust the air volume through a pressure loop control system.

Some people think that a building that is heated by pressurization will consume more energy than other heating systems. It is important to understand that a non-pressurization heating system depends on infiltration of cold air. Two problems occur that increase the use of energy in these type of systems;

1. There is a lag between the time that the cold air infiltrates and the time that it takes to heat it up so the building cannot consistently reach and sustain the desired temperature.
2. As the warmed air exits the system it rises and the cold air migrates at lower areas of the building creating stratification of temperature.

The discomfort that results from this arrangement and the inefficiency of indirect heating will actually mean higher energy cost than a direct-fired pressurization system.

The first step in dealing with the air needs of the powder system is the understanding of air-make-up heaters (AMU). An AMU is a device that supplies air and heat to the building. It provides air to compensate for the mechanical exhaust of the system equipment, preventing the negative air pressure inside that causes infiltration.

The AMU creates a slight positive pressure in the building (normally 0.01" water column/0.25 kg/M²). This pressurization creates a balance of the air being exhausted and the supply air. It allows the fans to perform without the problems associated with negative air pressure. It provides a lot of benefit that is often overlooked or poorly understood by coating system managers and owners. Pressurization combats other forces of nature that are detrimental to the powder system and the IAQ of the building.

The Benefits of AMU

There are many benefits to using AMU. The benefits listed below should encourage coaters to consider AMU to be an essential component to the success of a powder coating operation.

- prevents nuisance flame-outs of gas burners
- prevents back-drafts down exhaust stacks
- helps the fans in the system perform as intended without interference from crossdrafts
- prevents condensation on building steel, reducing the potential for dirt in the building and preventing rust
- provides uniform temperature in all areas of the building for optimum worker comfort and equipment performance

Direct Gas Fired Heating vs. Space Heaters

In addition to all of the benefits mentioned, an AMU heater is the most economical way to provide building heat. How is this possible? It's really very simple.

A direct fired system inherently puts 100% of the available heat into the air-stream. Indirect fired systems always have a chimney or flue that exhausts hot combustion gases out of the building and into the atmosphere.

The space heater has an initial peak efficiency level of around 56%. This is because approximately 20% of the fuel is lost in the flue gases

and additional fuel is lost to the heat exchanger, which is around 70% efficient when new. The heat exchanger breaks down over time and the efficiency level can drop to 40 to 50% overall efficiency.

Not only is the space heater inefficient, it cannot provide uniform temperature because it depends on infiltration of cold air for combustion. The combustion process requires approximately 10 parts of atmospheric air to 1 part natural gas. There is approximately 1000 Btu in a cubic foot of natural gas. A typical building may lose approximately 3,000,000 Btu/hr. in normal heat loss. This means that the space heaters will draw 3,000 cubic foot of combustion air every hour. This infiltration air for the combustion process must be heated so it adds to the normal building infiltration load. The cost for just the combustion air to support the space heaters is around \$0.95/hr.

Unlike the space heaters, the AMU heater does not bring cold air into the building for combustion. It also does not exhaust heated air. In a pressurized atmosphere, the temperature is much more uniform. The AMU heater does not use a heat exchanger, it does not exhaust and it does not bring cold air into the plant. The gas burner modulates according to demand and the efficiency approaches 100%. All of the heat value of the spent fuel is delivered directly into the building. Natural gas contains 8% water. During combustion, the natural gas generates "sensible heat" that contributes to temperature rise in the building. The water present in the gas generates "latent heat" that provides humidification in the plant. With a space heater, the latent heat is lost up the stack.

Without AMU, the natural force of the wind combines with the mechanical exhaust of the building to set up a situation where cold air enters and warm air exits. Cold air collects around the floor and warm air rises to the ceiling. Wasted energy collects around the ceiling while workers have cold feet at floor level. All of the burners are reacting to the cold air drafts along the floor, firing higher to offset the infiltration of cold air.

Positive pressure from an AMU provides controlled displacement ventilation. The building still breathes but now the air is fresher inside and the temperature is even. The fresh air from the AMU pushes out stale air and contaminants. The volume of air being displaced is controlled. Exhaust systems in washers and ovens work at the design volumes

without nuisance flame-outs or back-drafts. The “wind-tunneling” through the equipment that can occur with space heaters is eliminated. And the cost is 20 to 40% less than it is with indirect space heating.

Infiltration causes severe stratification of temperature. The floor is very cold, especially around dock doors and areas with poor protection from the outside. Space heaters, often used to heat a building, will run forever and never raise the temperature to an acceptable level in the really cold areas. Space heaters get their air for combustion from the cracks in the building. As the cold air enters, there is no possible way for that area to warm up. Instead, the heated air from the space heater rises to the ceiling along with the heat from the ovens and the washer. The floor may be around 45 °F while the ceiling is around

120 °F (5° to 49 °C) or higher. The space heater continues to run in an impossible effort to raise the temperature at floor level to a comfortable level. Cold air continues to infiltrate and Btu’s are consumed and lost as heat rises and cold air infiltrates.

So the direct fired air-make-up heater is different and more efficient than space heating. The air for combustion enters the heater, is raised to the set-point and blown into the building for efficient transfer of energy. Since the building is pressurized, the heat is much more uniform throughout. That 120 °F air that was lost up around the ceiling is now spread out around the plant, contributing to overall uniform comfort. In contrast to the space heater that allows continuous infiltration of cold air, the AMU takes just enough outside air to satisfy the building needs, raises the temperature to the desired set-point and distributes it evenly throughout the building. The burner modulates to provide only what is needed, no more, no less.

Variable Volume

As mentioned earlier, the condition within the building is dynamic and the system should be able to respond to the changes. A variable volume heater can be used to respond to the changes in pressure during operation.

A variable heater has two sets of inlet dampers, one for outside air and one for recirculation air. When the system demands 100% of the

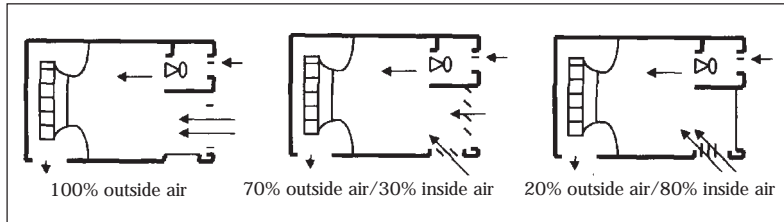


Figure 8-2 - Recirculating type Air Handler

heaters volume for make-up air the recirculation damper is in the full-closed position and the outside air damper is in the full open position. As the process exhaust requirements change, the dampers will modulate, opening and closing to vary the percentage of outdoor and recirculated air. As much as 90% of the air delivered can be recirculated. When the demand for outside air is low, the heater efficiently turns over the warm air already in the building instead of heating fresh air from outside. In the summer months the burner is turned off and the heater can deliver 100% outside air for ventilation.

The ratio of outside to inside air can be controlled manually with a dial or automatically with a pressure differential control. Experience has shown that the pressure loop control is somewhat slow reacting, so it may be difficult to maintain air balance when a lot of dynamic changes are common. The equipment can be fitted with a manual control with a production-time setting to allow sufficient make-up air from outside for all of the exhaust and a nighttime setting that recirculates a large percentage of the indoor air to reduce energy consumption. These settings can also be operated by a time clock.

Air Management Application Guidelines

When air supply systems are sized for a facility there is a list of issues that should be investigated and factored into the size and type of equipment to install.

- Contaminants generated within the system
- Goals for temperature and humidity control
- Design temperature range (winter/summer, high/low)
- Number of occupied hours
- Building construction and tightness of walls

- Building height and area
- Insulation “R” value
- Areas available for installation and limitations
- Climate (mild or severe)
- Total mechanical exhaust in CFM and locations of all exhaust stacks
- Existing condition of air in the building (exhaust, current air handlers, processes, etc.)
- Location of all process equipment within the building

With these details it is possible to determine the size and number of air handlers required, where they will be located, and what type of controls and features should be included.

Burner Sizing

The building should be analyzed to determine the highest possible demand for energy. Burner sizing will consider the air infiltration rate, the exhaust load, and door opening conditions. The burner will actually be sized for the coldest period of operation.

An example of an infiltration estimate:

Building Size:

200 feet (60 M) wide x 400 feet (120 M) long x 25 feet (7.5 M) high
 $200 \times 400 \times 25 = 2,000,000 \text{ ft}^3$ ($60 \times 120 \times 7.5 = 54,000 \text{ M}^3$)

The air infiltration rate can be determined from the chart below, which is based on a “normal” well built facility. Actual infiltration rates will be greater or less depending on the building construction and condition.

Air Sizing

To provide sufficient heat throughout the building and distribute it uniformly the air handling system must deliver more air from outdoors than the sum of all of the mechanical exhaust plus the infiltration rate.

Of course the area where the building is located and the construction of the building will affect any guideline for heating and airflow. Leaky building construction, large numbers of overhead doors that are opening and closing, and a cold local climate will raise the demand for heating energy. A tight building with limited door activity in a comparative warm climate will need more ventilation air capacity. Air changes per

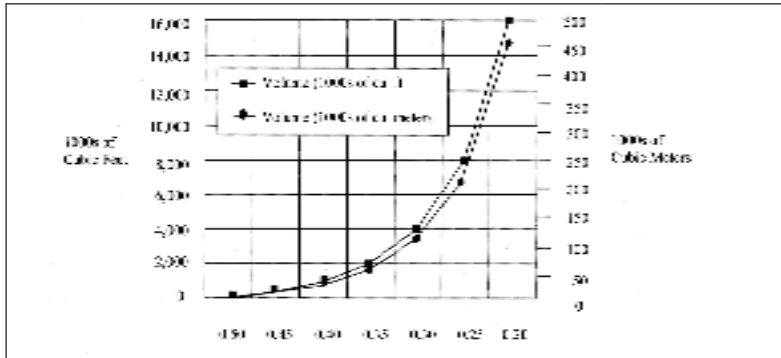


Table 8-1 – Air Changes/hour

hour can range from 1.5 to 6 to meet the building requirements in different conditions. A qualified supplier of air-make-up heaters can calculate the proper air change requirement. A good indicator is the average temperature differential between the discharge temperature and the room temperature. This value should normally be less than 10 to 12 °F (-12 to -9 °C).

In addition to the need for heat it is important to consider the need for summer ventilation. Powder coating systems can generate a significant amount of heat-gain in the building that must be turned over to avoid equipment problems and worker discomfort. In many cases it is desirable to add roof mounted exhaust fans to move the heat-gain from the building. So in addition to the supply air requirements for heat and the equipment exhaust the air handling system will now need the additional capacity for the roof exhausters. Cooling with ventilation may require as much as five air changes per hour.

The fans that are used for ventilation should be located as far as possible from the discharge of the air handler. They should be positioned above the washer and ovens to exhaust as much heat as possible.

Some guidelines for typical installations are listed below.

- Select an airflow rate that maintains an average discharge temperature at 10 to 12 °F (-12 to -9 °C) above the room set temperature.
- Select an airflow rate that exceeds the combined mechanical exhaust and infiltration rate by at least 10-20%.

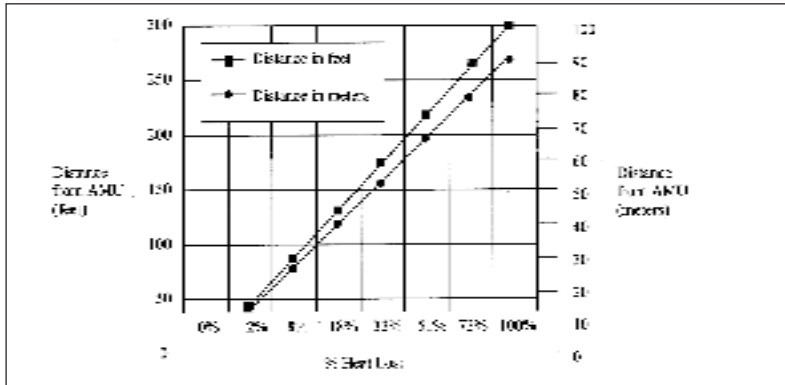


Table 8-2 – Heat Loss vs. Distance from Discharge

- When location restrictions prevent uniform positioning of multiple air handlers, a higher air change rate may be required.
- Where cooling with ventilation is a primary concern the air changes will be higher than what is required for heating alone.

Spacing of Air Handlers

For successful distribution of the air within the facility it is important to place the air handler(s) properly. Air will give up heat as it travels farther from the discharge point. If the distance from the discharge is too great an area may be below the desired building temperature. The chart below provides a guide to heat loss from distance.

The amount of distance between the discharge and the nearest wall or halfway to the next AMU can be referred to as “throw”. The chart below shows typical guidelines for “throw”. Spacing along these guidelines will help to manage uniform distribution of air and temperature.

Table 8-3 – Air Handler Spacing Criteria (Nomograph)

| Construction | “Throw” | | Insulation |
|--------------|---------|--------|------------|
| Tight | 90 M | 300 Ft | “R” = 10 |
| | 75 M | 250 Ft | |
| | 60 M | 200 Ft | |
| | 45 M | 150 Ft | |
| | 30 M | 100 Ft | |
| Leaky | | | “R” = 1 |

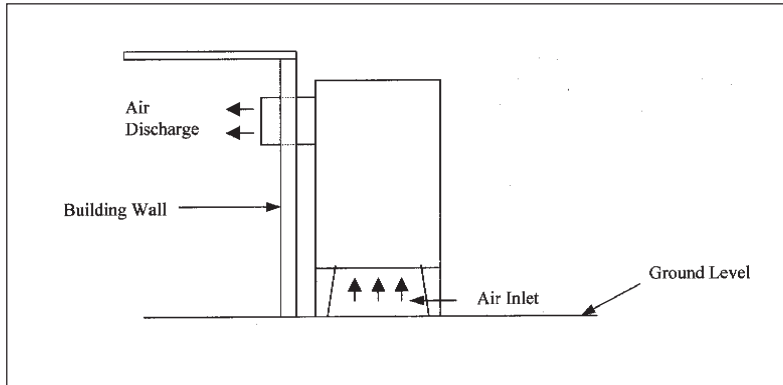


Figure 8-3 - Upright Installation of AirHandler (side view)

Mounting an Air Handler

Air handlers can be constructed for mounting in a horizontal position or in an upright position. They can be roof-mounted, mounted on the ground along the side of the building, or suspended from the roof inside the building. The style and location depends on the building type, the availability of land, and the cost of installation.

Typically, an air handler for a powder coating system works best when mounted in the upright position. The discharge point is near the top of the building, allowing for simple diffusion of the air through a discharge head or ductwork if it is necessary. The discharge velocity is less likely to interfere with the airflow of the individual pieces of equipment. The inlet is underneath the unit so it is less likely to entrain rain or snow from the prevailing winds. It takes up less space than a horizontal installation. An important consideration when selecting an upright unit is the need to keep the inlet up off of the ground to prevent excessive entrainment of moisture or dirt.

The height and the direction of the discharge is another important issue. Air discharged too low (less than 15 feet/5 meters) above the floor may cause uncomfortable drafts to people nearby in the winter. The air speed from the fan feels cool even though the air is warmed. In the summer months the air blown onto the workers feels good.

Air that is discharged horizontally at a height greater than 40 feet (12 M) above the floor may cause stratification of temperature and poor dilution of the air near the floor.

Filtration

The level of filtration for air being supplied to a powder coating system depends on the type of system and the quality requirements of the finished parts. The inlet of the air-make-up should always have a 30% efficient polyester filter bank to catch larger contaminants and prevent them from entering the building. If the discharge of the air handler is into the general plant environment it may not be necessary to have any additional filtration.

When the discharge is into a walled-off spray room or “clean room” the filtration must be very thorough. Discharge ductwork is used with a series of 90% plus efficient bag filters and a low discharge velocity. The filter frames must be designed to seal the edges so that the air supply cannot pass around the filter. All filters should be monitored and changed frequently enough to avoid putting excess static pressure on the heater.

It is also a good idea to locate the air handler inlet and discharge in a position that is relatively clean to avoid pushing contamination towards the coating line.

Summary

Air management is a vital part of any coating system. Without the proper consideration of airflow and air supply the system cannot function properly. Product quality, system efficiency, worker comfort, proper building Indoor Air Quality (IAQ), and system maintenance cost is affected by the air volume, velocity and direction.

When a powder coating system is designed the plan should include air-handling equipment to provide uniform heating and ventilation and ensure proper operation of the process equipment.

4 Surface Defects

Rejects from coating lines can come from a substrate defect, a surface contaminant or a coating material defect. Process controls should be implemented upstream of the coating line to prevent a defective substrate from entering the line. If a substrate is defective and has entered the coating line, it is important to recognize the source of the blemish and not waste time trying to fix the coating process to correct a pre-existing substrate condition.

Dirt on the surface of a coated part is a major concern for all coaters. Dirt may come from the air around the spray environment, from the application equipment or it may be in the coating material.

If a defect is from contaminated coating material or manufacturing by-products that have not been removed by the cleaning process it will be evenly distributed and, if it is an external source, the defect will more likely be random.

Dirt in a powder coating can be screened out. Rotary sieves or vibratory sieves can be used to filter powder fed from the collector module. Integrated screeners can be built into collector modules. Even an all-manual operation can screen powder by putting it through a stainless steel screen before loading it into the feed hopper. Powder should always be screened. Reclaim needs to be screened to eliminate dust that has entered the booth. Virgin material should be screened to make sure that there are no chips or contaminants in the box.

Dirt from ineffective pretreatment can usually be corrected by changes in the process or control of the pretreatment system. Soils that are on the part from the manufacturing process that cannot be removed by a spray washer can usually be tracked to the source so a change can be made to eliminate them.

Air borne contaminants are the hardest to track and eliminate because they can come from so many different sources. Keeping a clean environment around the system is one of the best ways to reduce air borne dirt.

Electrostatically applied powder can entrain airborne dirt and deposit it on the parts.

The list below names some of the common sources of airborne contamination.

1. People – Air sampling of enclosed coating systems has shown that as much as 80% of the airborne contamination comes from the clothing, hair and shoes of personnel.
2. Nature – Pollen, road dust and other outdoor dirt are sometimes brought into the plant through doors, windows and unfiltered air supply systems.
3. The Building – Concrete floors may wear and give off dust.
4. Manufacturing – Mechanical operations in the manufacturing process may generate dust, metal shavings, or wood dust.
5. Process Equipment – The conveyor, the oven, the washer or other operations within the coating line can generate or concentrate dirt that will create a defect.

With all of these potential sources, the job of coating a part with no defects is a challenge to say the least. Here are some ways to help control dirt on coated parts. The level of dirt prevention that an operation adopts is directly related to their quality standards. In many general industrial applications it is not necessary to reach the highest level of cleanliness. However, in automotive facilities or other industries where quality levels are very demanding it may be necessary to adopt all of the following suggestions.

1. Restrict access to the coating area or clean room to essential personnel as much as possible. Have all entrants to the powder room put on non-lint paper suits, hairnets and shoe covers.
2. Isolate the coating application area from the rest of the plant and supply filtered air to the enclosure that will create a slight positive pressure in the room to prevent air from infiltrating through the product openings.
3. Have the concrete floors sealed in the area where workers put on their paper suits and in the powder room. Build a vestibule at the entrance to the powder room and add deionizing air in the vestibule to neutralize the workers before they enter.

4. Clean **all** surfaces in the room as frequently as necessary to avoid an accumulation of dust.
5. In overhead-conveyorized systems, use an inverted box track conveyor or a sanitary pan under the conveyor. Use an automatic lubrication system with a dry-film, penetrating lubricant and do not over-lubricate. Clean the conveyor and chain components regularly with brushes or water blasting.
6. Filter the return air in the oven by installing a filtration bank in the return air opening of the burner box. Clean oven interior regularly (once a week).
7. One of the keys in controlling dirt is to use good recording and tracking of dirt rejects. Fiber, metal shavings, paper, and dust are examples of types of contaminants. Rejected parts should be recorded and categorized by the type of defect. The source of the dirt should be tracked and eliminated.

Dirt Control Plan

The best way to control dirt rejects is a formal dirt control plan. This holds for installations that have very high quality standards and find that the dirt level is too high. This involves the formation of a dirt team and establishment of specific goals to be achieved.

Dirt Defect Analysis & Reduction

In order to analysis and reduce dirt on the product, the dirt team starts out with the development of a set of objectives. The objectives are the foundation of the activity of the dirt team.

Objectives

First of all, it is necessary to categorize dirt rejects in specific terms. Generally listing a reject as idirtı will not help to lead to reduction of contamination. Only when the contaminant is accurately identified can the source be determined. Cotton fiber, condensate, copper, sulfur, phosphate, metal shavings, rust flakes, old paint chips, etc. These are acceptable categories of dirt rejects.

When the dirt is identified, it can help to lead to the source. Once the source is known, corrective action can be taken. The steps to be followed are:

1. Characterize contamination that causes defects
2. Identify the most probable sources
3. Establish appropriate corrective action to minimize or eliminate problems

Requirements

Corporate, plant and paint area management must be committed to dirt training, analysis and reduction activities for the coating system. The shop is recognized and treated as a separate, special factory environment. Coating processes are monitored for consistency. It is essential to follow these two principals:

1. Must be ongoing process
2. Must have management support

If the process starts and stops the results will not be satisfactory. If management does not support the effort its effectiveness will be limited.

Dirt Control Process

The process of dirt control involves the application of continuous improvement techniques. Development of charts that identify the problems and formal problem solving continually reduce the sources of dirt.

- Continuous improvement techniques are applied to the process
- All coating line personnel are aware of how their work performance impacts the product

Continuous improvement is a formal process that seeks opportunities for better performance. **All** coating line personnel, including rackers, applicators, quality control workers, packagers, hi-lo drivers and technicians need to understand their role in quality output.

The Dirt Analyst

A dirt analyst leads this effort. The dirt analyst coordinates and administers a continuous effort to reduce rejects. He/she should meet the following criteria:

- A production worker
- Not subject to job rotation

- Highly motivated
- A good communicator
- Provides training for others
- Applies Statistical Process Control methods to monitoring dirt levels
- Develops facility and process investigative techniques

Facilities Maintenance Relating to Dirt

It is essential to practice planned maintenance to keep the system running smoothly and keep the yield high. Planned maintenance means having a schedule for the necessary cleaning, adjusting and repair of the system components. The time, materials and people required for the job are determined and assigned to maintenance as a regular part of their job. The line operators can often perform maintenance at the end of each shift. Here are some examples of things that are part of the planned maintenance program.

- Oven & booth
 - Cleaning
 - Filter Changes
 - Inspection/replacement of wear parts
- Washer
 - Chemical titration
 - Nozzle maintenance
 - Clean screens
 - Empty bag filters
 - Descaling
- Conveyor
 - Check lubricator reservoir
 - Clean chain and rail
- General housekeeping
- Problem solving techniques
- Preventive maintenance

Dirt reduction is related to focused cleaning and maintenance. Focused cleaning requires allocation of time and resources.

Process Monitoring

Process monitoring is necessary to chart results. Documentation provides the necessary information used to make progress.

- Dirt count
 - Count dirt defects on a consistent number of parts each day, randomly selected.
 - Use a Flow Diagram: pretreat-prime-base coat-clear coat-cure
 - Arrange on SPC chart (upper control, mean, lower control)
- Dirt identification (Pareto)
- Dirt reference handbook
- Dirt analysis data sheet
 - Date
 - Time
 - Process
 - Color
- Communicate results

Use SPC Chart as a Monitoring Device

Statistical Process Control (SPC) is the tool that establishes the operating guidelines.

It is used to analyse a process or its output. Process outputs are monitored to evaluate the operation. If the operation needs adjustment it will be revealed by the process monitoring methods so that corrective action can be taken before large amounts of production are made with defects. The technique involves predicting output based on control of variables, sampling, feedback from samples, and controls that keep the process within acceptable range. Pretreatment, application, and curing need to be monitored and controlled for predictable results. Keep the following ideas in mind.

- Recognize when process is out of control
- Have mechanism to correct out of control process
- Correlate process changes with trend in dirt levels

Control of the powder material, the pretreatment chemistry, the equipment, the environment, and the people that run the system is needed for the highest possible level of quality.

The development of a formal SPC program begins with the establishment of a steering committee. Like the dirt team, the steering committee sets objectives for the group. SPC requires some training in data collection and reporting techniques. The team will learn these techniques, use them to break down the process and select control

| | | |
|-----------------|---|---|
| Powder Material | <ul style="list-style-type: none"> • Powder as received • Powder film | <ul style="list-style-type: none"> • General condition, particle size, moisture content, fluidization pressure, hiding ability • Film thickness, color, gloss, hardness, texture, uniformity, performance |
| Pretreatment | <ul style="list-style-type: none"> • Water quality • Chemicals • Soils to be removed | <ul style="list-style-type: none"> • Hardness, purity • Composition, concentration • Organics, encrustations, processing materials, oxides, etc. |
| Equipment | <ul style="list-style-type: none"> • Pretreatment system • Dry-off oven • Powder application • Powder booth & recovery • Racking • Air compressor • Conveyor | <ul style="list-style-type: none"> • Pressures, process times, solution temperatures • Air temperature, part temperature, process time • Voltage, current draw, flow rates, atomizing pressure, gun-to-target distance, nozzle type, ground • Air velocity, filter condition, amount of powder in the collector • Size, design, number of parts, type of contact • Air volume, pressure, moisture content • Cleanliness, line speed, hanging centers |
| Environment | <ul style="list-style-type: none"> • Plant • Powder application • Ovens • Load/unload area • QC inspection area | <ul style="list-style-type: none"> • Indoor air quality, temperature, humidity, lighting, housekeeping, air flow, AMU • Temperature, humidity, lighting, cleanliness, air flow • Air flow, cleanliness • Organization, work flow, packaging • Lighting |
| People | <ul style="list-style-type: none"> • Capability • Technique | <ul style="list-style-type: none"> • Skills, commitment, physical health • Position of product in booth, manual application, automatic set-up |

Table 1 – Typical Variables that Affect Output

characteristics. Gauges are developed to provide the necessary measurement of the characteristics selected. Data is collected with the gauges and used to build charts. The charts are read and used for corrective action when necessary. The results are monitored to verify the results of the program.

Dirt Identification

Dirt can be identified through the use of microscopes. Magnified pictures and real size pictures can be used to develop a reference book for dirt identification. Only when the defect is identified can the best possible solution be discovered.

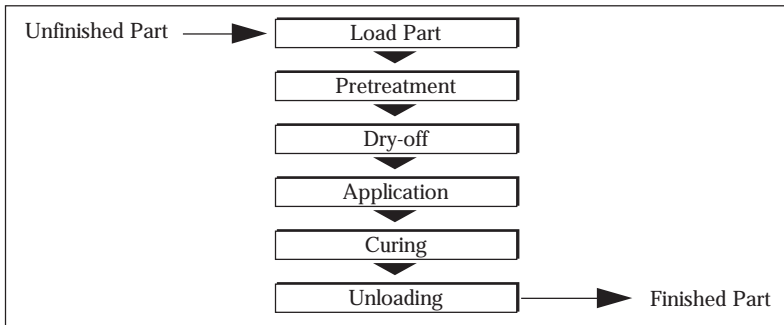
- Use shop microscope to identify defects on-line (paint chip, cotton fiber, sanding dust, gun spit, synthetic fiber, metal shaving, oil, etc.)
- Remove sample of defect for further analysis
- Use stereo microscope to identify difficult defects and to create documentation
- Use scanning electron microscope to analyze defect and compare to reference for positive ID

Process Analysis

Diagrams and charts are used to analysis the process for the source of the identified substance.

- Use Flow Diagrams to find the root cause of the dirt
- Use Cause and Effect Charts as tools to guide you

Figure 8-3 - Flow Diagram



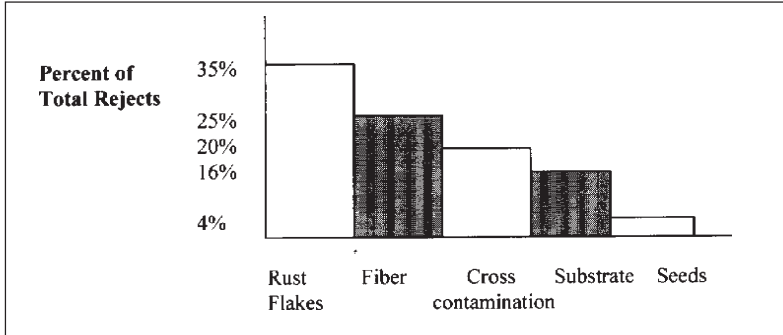


Figure 8-4 - Pareto Chart of Rejects

Monitor Trends after Process Changes

Monitoring is essential to chart the impact of changes. Pareto charts can be used to compare the relative importance of the various problems.

- Work on biggest problem first
- Make only one change at a time
- Allow enough time and take a big enough sample for the trend to be evident (minimum 20 days)
- Recalculate Mean & Control limits
- Update Pareto Chart
- Go on to next biggest problem

Dirt Team

The dirt team works together to study problems, develop action plans, implement solutions and monitor the results.

- Members come from all areas of the paint operation.
 - Dirt analyst
 - Production operator
 - Production supervisor
 - Process engineer
 - Maintenance
 - Quality representative
 - Suppliers
 - Management

- Organization for dirt reduction
- Identifies problems and works on solutions
- Focused on continuous improvement

gun-to-target distance, flow rate and gun position is all very important in powder spray application. Yet many operations use the same gun settings for a wide variety of product. To avoid dry-spray, runs, light coats and excessive film, guns need adjustment for part geometry and density. Parts can be grouped into families with similar characteristics but unless all of the parts are very similar, some adjustment is necessary to achieve the best possible results. If a part is run by the spray guns at a distance of 8" and a second part is run by at 12" with no flow adjustment, the film thickness and texture will be different. Some materials must have a consistent film thickness to provide the proper color and gloss.

The same rules apply to other areas of the operation. The washer chemistry must be controlled within a certain range, pressures may need adjustment, etc. Cure ovens need cleaning, calibration, filter changes and possibly temperature adjustment from one product to the next.

Rules for Development of Process Control

1. Identify the performance variable
2. Determine an acceptable range of performance
3. Develop a plan to maintain the predetermined performance range
4. Monitor results and adjust as necessary

The idea of process control is not new. But many coating operations do not practice good control techniques. For example, everyone should recognize that good ground is critical to the performance of electrostatics. Yet many companies do not have a plan for checking and confirming that they are consistently providing good ground. In fact, many coaters do not have good ground and don't realize it because they do not have any provision for routine measurement!

7 Summary

Quality on the coating line is primarily common sense and hard work. Follow these guidelines and the system should perform at the desired level.

1. Select the right equipment to meet quality goals.
2. Operate and adjust the equipment to maintain peak levels of performance on all parts.
3. Control the process to reduce variance to the lowest possible level.
4. Clean and maintain the system on a scheduled basis that is consistent with quality goals.

Consistent maintenance of film thickness, color, gloss, texture, coverage, hardness and corrosion resistance comes from knowing what it takes to achieve it and controlling the system variables to get there. Learn everything you can about your equipment and process and run it with tight control.

Remember that the sources of defects do not rest. Airborne dirt, condensate, and rust are at work all the time. The only way to beat them is to be thorough and relentless. Set your standards high. Do not accept performance that is inferior to anyone else who does the same job. Make your goal to be the best in your business.

5 Racking

Design and maintenance of the fixtures that hold the parts as they travel through the coating system is frequently a source of quality defects. In order to provide the highest possible level of efficiency and quality a rack should be thought of as a tool.

Issues to Consider in the Design & Care of Parts Racks

- Racks will be used in an industrial environment; make them sturdy.
- If the parts can swing on the rack, they may hit each other in the oven and cause a blemish in the coating.
- Tubing used for rack frames can trap water in the washer; if it boils out in the cure oven it will stain the coating.
- For electrostatic application, contact points must always be clean to provide good ground.
- Coating build-up on racks can crack and create dirt defects.
- Coating build-up on contact points will interfere with electrostatic attraction.

To maintain a low level of defects on the coated parts, the tooling must have a low level of defects. Good original design and good rack maintenance will contribute to yield. Electrostatic contact points should be designed to make sure they provide a certain ground to the parts. Missing contacts should be replaced and bent frames straightened so that the work package is consistent in relationship to the application equipment. Heavy build-up on racks should be avoided by a planned schedule for stripping racks and by making sure that there are enough racks to manage production while racks are in the strip cycle.

6 System Process Controls

There are many variables that can affect the performance of coating system. Each performance variable must have a defined process control method in order to maintain peak efficiency. For example, the

gun-to-target distance, flow rate and gun position is all very important in powder spray application. Yet many operations use the same gun settings for a wide variety of product. To avoid dry-spray, runs, light coats and excessive film, guns need adjustment for part geometry and density. Parts can be grouped into families with similar characteristics but unless all of the parts are very similar, some adjustment is necessary to achieve the best possible results. If a part is run by the spray guns at a distance of 8" and a second part is run by at 12" with no flow adjustment, the film thickness and texture will be different. Some materials must have a consistent film thickness to provide the proper color and gloss.

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IX

System Maintenance

| English/Metric Conversions | |
|----------------------------|---------------------|
| English | Metric |
| 1 inch | 2.54 centimeters |
| 1 foot | 0.3048 meters |
| 0.3937 inches | 1 centimeter |
| 3.281 feet | 1 meter |
| 1 ounce | 28.35 grams |
| 1 pound | 0.4536 kilograms |
| 0.205 pounds | 1 kilogram |
| 1 U.S. gallon | 3.785 liters |
| 0.2642 U.S. gallons | 1 liter |
| 1 sq. foot | 0.0929 sq. meters |
| 1 cubic foot | 0.0283 cubic meters |
| 35.31 cubic foot | 1 cubic meter |
| 1 Btu | 1,054.8 joules |
| 1 Btu | 0.2520 kg.-calories |
| 1 sq. inch | 6.452 sq. cm. |

| Temperature Equivalents | | | |
|-------------------------|--------|------|-----|
| °F | °C | °C | °F |
| - 10 | - 23.0 | - 20 | - 4 |
| 0 | - 17.8 | - 10 | 14 |
| 10 | - 12.2 | 0 | 32 |
| 20 | - 6.7 | 5 | 41 |
| 30 | - 1.1 | 10 | 50 |
| 40 | 4.4 | 15 | 59 |
| 50 | 10.0 | 20 | 68 |
| 60 | 15.6 | 25 | 77 |
| 70 | 21.1 | 30 | 86 |
| 80 | 26.7 | 35 | 95 |
| 90 | 32.2 | 40 | 104 |
| 100 | 37.8 | 50 | 122 |
| 110 | 43.0 | 60 | 140 |
| 120 | 49.0 | 80 | 176 |
| 130 | 54.0 | 100 | 212 |
| 150 | 66.0 | 120 | 248 |
| 200 | 93.0 | 150 | 302 |
| 300 | 149.0 | 180 | 356 |
| 400 | 204.0 | 200 | 392 |
| 500 | 260.0 | 250 | 482 |

Overall system maintenance affects worker comfort, productivity, product quality, and operating cost. The least expensive and most effective maintenance of a coating system is a formalized planned maintenance program. Planning what will be done, who will do it, what resources they need to do it with and committing the time and resources to the task is the correct way to keep the system running well. Fixing things when they break is the most expensive and least effective way to operate a system.

Throughout this manual there are references to specific maintenance practices and the importance of keeping the system in good working condition. There are often situations where systems are not properly maintained and excuses are offered; "... we are too busy to take time out for maintenance," "... management does not supply us with parts or time for maintenance." In reality, there is no good reason for not maintaining the system. When it is new it runs correctly. When it is used it will gradually deteriorate. To keep production at the best possible level and meet quality goals requires a well designed planned maintenance program that is performed on a regular basis.

Planned maintenance starts with the development of a Standard Operating Procedure (SOP). Development of a planned maintenance SOP involves certain steps.

Step 1: What needs to be done?

Study the process with these questions in mind;

- what components of the system need periodic cleaning?
- what components of the system need to be replaced periodically?
- what needs to be lubricated?
- what items need to be inspected?
- what items need to be tested?

Step 2: How often?

Determine how often these tasks need to be performed in order for the system to run at peak efficiency.

Step 3: How long will it take?

Determine how many man-hours are required for each task.

Step 4: Who will do it?

Select the employee(s) who is/are best suited for each task.

Step 5: What materials are needed?

List the materials that will be required for each task.

Step 6: When will it be done?

Determine when each task will be performed.

Step 7: What tools will be required to do the work?

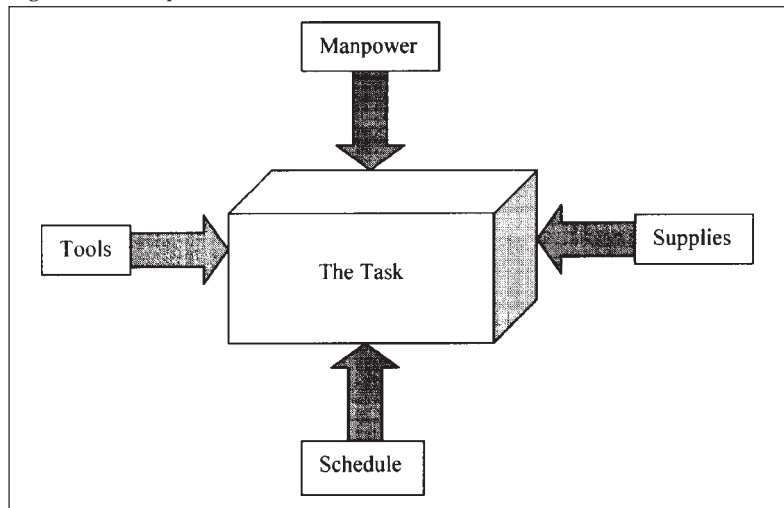
List all of the equipment that will be necessary to conduct the maintenance plan.

With the list of what, who, when, where and how the job will be done it is possible to design a plan, schedule the activities, maintain a supply of the materials needed and keep the system operating properly.

A Standard Operating Procedure is a document that clearly defines all aspects of a specific maintenance requirement.

- Task
- Frequency
- Supplies

Figure 9-1 – Requirements for Planned Maintenance



- Tools
- Objectives
- Safety precautions
- Steps of the process

Like any plan, the maintenance SOP must be monitored for effectiveness and adjusted if necessary. The following list is the recommended tasks that are typically required for a powder system and the frequency that they should be performed.

Other items may be needed in a particular system. It is important to identify the maintenance items that affect system performance and schedule the activities for servicing them.

In addition to the maintenance performed by company personnel, it is advisable to have an outside contractor come in bi-annually to inspect, clean, calibrate and adjust the mechanical components of the system. A qualified contractor can check all belts for wear, inspect and clean fan blades, dismantle, clean, inspect and adjust all burners, inspect the pumps and motors for wear, and test all of the vital safety and operating controls. This provides an additional layer of protection from emergency break-down and keeps the system operating at peak efficiency

Summary

Do not underestimate the value of good maintenance. Proper attention to the systems working components can be the difference between failure and success of a powder coating system. Once a plan is in place and the work is performed regularly, it takes very little time away from production and makes production time more profitable.

| Equipment | Maintenance Task | Frequency |
|--|--|----------------------------|
| Conveyor | Inspect drive chain (even if you have automatic lubrication) and manually lubricate | Weekly |
| | Provide automatic lubrication of wheels, trolleys, and chain; inspect the lubricator and fill reservoir | Weekly |
| | Inspect and lubricate the drive unit frame | Monthly |
| | Lubricate back-up rollers on the drive unit | Monthly |
| | Lubricate take-up components | Monthly |
| | Inspect belts and pulleys on drive unit for wear | Monthly |
| | Lubricate roller and wheel turns | Monthly |
| | Inspect and lubricate all switches on power & free | Monthly |
| | Empty and refill lubricant reservoir | Bi-annually |
| | Lubricate drive unit bearings | Quarterly |
| Lubricate chain drive sprocket | Quarterly | |
| Washer | Inspect and clean tank screens | Daily |
| | Inspect, clean, adjust and change nozzles as needed to avoid plugging | Weekly |
| | Lubricate bearings and lip seals on solution pumps | Monthly |
| | Lubricate fan shaft pillow blocks | Bi-annually |
| | Lubricate fan motor bearings | Annually |
| | Inspect and clean tank floors when sludge excess 2" | As required |
| | Flush out external heat exchangers | As required |
| | Inspect internal burner tubes | Whenever the tank is empty |
| Ovens | Remove fallen parts from oven | Daily |
| | Clean oven interior | Weekly |
| | Inspect all burner flame failure system and ignition system | Weekly |
| | Inspect and clean or replace burner combustion filter | Weekly |
| | Inspect the interior of the burner box for carbon build-up | Weekly |
| | Lubricate fan bearings | Monthly |
| | Test safety shut-off valves | Monthly |
| Open fuel line drip leg and empty sediment | Monthly | |
| Powder Application Equipment | Thoroughly clean all items in the powder path (guns, hoses, pumps, attachments, inserts, pumps & pick-up tube) | Every shift, minimum |
| | Inspect all wear parts | Every shift, minimum |
| | Inspect feed hoses for wear or plugging | Every shift |
| | Inspect the charging electrode | Daily |
| | Check gun output current readings | Daily |
| | Check and clean all gun cables and connections | Weekly |
| | Clean and inspect feed hopper level probes | Weekly |
| Clean and inspect fluidized bed membrane | Weekly, minimum | |



IX

System Maintenance

| Equipment | Maintenance Task | Frequency |
|--|---|------------------|
| Powder Recovery Equipment | Empty sieve waste container | Every shift |
| | Clean interior of booth | Daily, minimum |
| | Check powder transfer pump pressure | Daily |
| | Check fluidization in collector module | Daily |
| | Check filter monitor gauges | Daily |
| | Check rotary sieve bearing air seals | Daily |
| | Clean exterior of booth and recovery system | Weekly, minimum |
| | Inspect blower gaskets and collector module seals | Weekly |
| | Clean and inspect transfer pumps and hoses | Weekly, minimum |
| | Clean and inspect rotary sieve housing | Weekly |
| | Clean and adjust cartridge back-pulse | Weekly |
| | Clean feed hopper vent hose | Weekly |
| | Inspect cyclone for impact fusion or leaks | Weekly |
| | Clean and inspect collector fluidized bed membrane | Monthly |
| | Test fire detection system | Monthly |
| | Lubricate fan bearings | Monthly |
| Inspect fan belts and pulleys for wear | Quarterly | |
| Change cartridge filters (as needed) | Annually is typical | |
| Air Compressor & Air Piping | Change oil | 500 hours |
| | Drain moisture from air receiver | Daily |
| | Check filters and drain as necessary | Daily |
| | Blow out drain legs | Daily |
| | Check air dryer for proper operation | Daily |
| | Check air piping for leaks | Weekly |
| | Check control devices | Weekly |
| | Inspect inlet filters | Weekly |
| | Inspect belts and pulleys | Monthly |
| Inspect and test air receiver and surge tanks for proper operation | Bi-annually | |
| Gun Movers | Lubricate moving parts | Monthly |
| | Lubricate bearings and drive chains | Quarterly |
| | Check gear reducer lubricating oil and replace if necessary | Bi-annually |

Troubleshooting problems in the powder operation may be necessary from time to time in spite of good process controls and operating procedures. Troubles can occur in application, pretreatment and curing. Knowing what to look for helps to speed up the process of correction.

1 Application Problems

Problems with powder charging or delivery will make it more expensive and difficult to apply the material to the part. Many times these problems can be corrected by a review of the basic function of the application system to see what is wrong. This troubleshooting section covers some of the common mistakes that cause difficulty in the application of powder coatings.

Poor Charging

When it becomes unusually difficult to get powder into the inside corners (Faraday cage areas) there are three common things that should be checked.

1. Grounding
2. Powder flow rate
3. Voltage

Grounding may be lost from excess build-up of coating on the hangers. Measure the resistance from the part to the conveyor rail with an ohmmeter. If the resistance is greater than 1 megohm, the path to earth ground is not adequate. Check the components of the racking arrangement, find the insulated component and clean it to make good contact.

Excessive powder flow rates will cause a reduction in charging efficiency. Check the gauges and reduce the flow rate.

The voltage at the gun tip needs to create a field of high potential. Check voltage at the gun tip to make sure that it is compatible with the gauge.

The Faraday cage effect describes the problem with getting the powder to adhere to the surface of an inside corner. This is the result of resistance created by the presence of an electrostatic force. The elec-

trostatic force is attracted to the prominent areas of the part where the resistance is low. Free ions and powder film build quickly on these more prominent surfaces and create additional resistance to penetration.

Faraday cage effect can be reduced by limiting the current draw of the gun, by using the correct nozzle for the task, and by control of the flow rates and gun-to-target distance.

Back ionization

Back ionization occurs when the electric field on the part surface reaches a point where it begins to ionize the air under the powder film. Positive ions are released, creating ruptures in the film, repelling the powder and causing a blemish that is commonly called a "star." The potential causes are:

1. excessive voltage (high current draw)
2. the gun is too close to the part (high current draw)
3. too much film build (too many free ions on the surface)
4. application over an already coated surface (dielectric of coating creates resistance)
5. poor grounding of part (no path to ground for ions)

Preventing back ionization requires control of current draw. If the current draw is too high the part surface will not be able to take the number of ions arriving. Voltage levels, gun-to-target distance, the presence of ion collectors or the control of the load line inside the gun affects control of current draw. Lower voltage, greater distance to the target, automatic current control or ion collectors can be used to reduce the potential for back ionization.

Surging of the Powder

- Powder surging from the gun can be caused by:
- the compressed air supply is too low
- the compressed air supply fluctuates when other building equipment is in use
- the compressed air supply has moisture or oil in the line
- the powder hose is kinked

- the powder hose is too long
- impact fusion is interfering with powder flow
- delivery rate is too high
- the powder is not properly fluidized
 - too high – clumping, excess impact fusion, gun spits, powder comes out of top of the feed hopper
 - too low – inadequate supply, inconsistent flow

Control of the compressed air in the system requires training. All powder system operators should have an understanding of the pneumatic controls and how to properly adjust them. Hoses should be inspected and changed when they are worn. The powder output should be observed and adjusted if necessary.

Inconsistent Powder Delivery

Powder must be delivered at a consistent flow rate with a consistent pattern to charge properly and maintain a uniform film. Inconsistent patterns from the gun may be caused by some restriction in the powder path.

- plugged powder hose
- excess impact fusion
- bent electrode
- obstruction of the powder hose

Inspect the hoses to make sure that they are clean and that they are not kinked.

Powder flow rates that are too high will cause:

- high impact fusion
- excessive wear of replacement parts
- low transfer efficiency
- poor penetration
- poor electrostatic wrap

Powder flow rates that are too low will cause:

- gun spits
- inadequate film build
- poor penetration

Atomizing air that is too high can cause:

- low film build
- poor penetration
- poor transfer efficiency
- fat edges

Fluidizing air that is too low can cause:

- gun surging or puffing
- a need for higher pump pressure (more wear on gun parts)
- uneven film build
- poor transfer efficiency

Powder Flow

Since the flow of powder is accomplished with compressed air, a flow problem is related to the air supply, air controls, or blockage of the powder path. To troubleshoot a flow problem, you should follow this process:

1. Be sure that the compressed air supply is clean and dry.
2. Be sure that the powder hose is not too long.
3. Be sure that the powder supply air, forward air and fluidizing air are properly adjusted.
4. Check the feed hopper to be sure it is adequately full and fluidized.
5. Check the supply hoses and venturi to make sure they are clean and leak free.
6. Check venturi and gun inserts for wear and change if necessary.

If all of these conditions appear to be all right, check the controls to make sure that they are in proper working condition.

Film Build Control

Film build control is a critical issue; if the film is thicker than necessary it is a waste of material, if the film is too light it may be defective. Film thickness should be monitored on a regular basis. To avoid film build problems, the equipment must be maintained according to the manufacturer recommendations.

Film cannot be controlled if the operating issues that contribute to transfer efficiency are not followed. If all operating parameters are under control, proper gun adjustments must be determined and maintained in order to control film build.

1. Film too thick – adjust supply delivery pressure down
2. Film too thin – adjust supply delivery pressure up
3. Film inconsistent – adjust voltage, gun position, stroke or conveyor line speed

Impact Fusion

A certain amount of impact fusion is common. Powder will pick up some frictional charge and collect along the powder path. If impact fusion is excessive and becomes a nuisance, it is probably related to the powder itself or moisture.

If most of the powders being used in a line are working well but one or two impact-fuse excessively, the supplier of the powder should be consulted.

If all or most of the powders in a line are fusing excessively, the powder is moist or being delivered at too high a pressure.

Cross Contamination

Cross contamination occurs when the system has not been completely purged of one color before another color is introduced. To avoid contamination the powder booth, recovery system and everything in the powder delivery path must be completely cleaned. Since most powder systems feature dedicated feed hopper and cartridge modules, the problem is usually related to the powder supply hose, lift venturis or gun barrel.

If contamination is a problem, color change procedures should be examined to determine where the flaw is and it should be corrected. All surfaces in the area should be cleaned, including the top of the booth. Dedicated lift venturis and hoses can help to reduce clean up labor and contamination.

In a cyclone system, contamination may be related to poor airflow through the ductwork. Cyclone duct should be briefly purged before starting a new color. Poor flow in the recovery duct is related to poor

design. The duct should be cleaned periodically with some type of mild abrasive such as plastic shot.

Sparks, Shocks

There are three possible causes of sparks or shocks from the powder equipment:

1. Poor grounding of the part or some component of the system.
2. Defective voltage cable or gun barrel.
3. Operator misuse.

Most of the time, a spark is the result of a poorly grounded part. Since the part is not grounded, it stores voltage to a certain capacity when the charged powder is sprayed. It will eventually discharge to the nearest ground; the booth, the gun or the operator. Since a spark can produce a fire, proper grounding is a safety issue as well as an efficiency issue.

Also, all components in the powder application area must be grounded or charged. Remember, grounding can be checked with an ohmmeter and resistance of 1 megohm or greater indicates a problem.

2 Adhesion

Poor adhesion is usually related to poor pretreatment or under cure.

1. Undercure – Run an electronic temperature recording device with a probe on the part to ensure that the metal temperature reaches the prescribed cure index (Time at temperature).
2. Pretreatment – Perform regular titration and quality checks to avoid a pretreatment problem.

3 Outgassing

The term outgassing is a reference to the release of trapped air in a cast substrate during the cure cycle. Porosity in the casting traps air. When the casting is heated, the air expands and blows through the partially gelled coating, leaving a small defect like a pinhole.

Outgassing is a serious problem for powder coaters. The severity of the problem is dependent on the type of casting and the quality of the

casting. Generally, aluminum is not too bad, while zinc die cast can be more of a problem and sand castings are the worst. Methods for dealing with this problem are limited.

If a manufacturer has control over the casting process, they can work to minimize the contamination in the casting process, x-ray castings for porosity as a process control measure and use an impregnator to fill open porosity in the cast surface. Many times these measures are not available or not practical.

Two widely used methods of dealing with outgassing are preheating and the use of "outgassing forgiving" powders.

Preheating means bringing the part to a temperature in excess of the cure temperature prior to coating. For example, running the part through the dry-off oven at 450 °F and curing at 350 °F. The theory is that the trapped air will escape in the preheat and no more will come out in the cure oven. Actual field evidence is that this can be an effective way to reduce the damage of outgassing by a large margin.

Outgassing forgiving powders are designed to provide a longer flow cycle so that the air can escape before the powder has gelled. This also has been demonstrated to be an effective way of reducing outgassing.

4 Masking

When a manufactured part is powder coated there may be certain areas of the surface that must be free of coating. For example, threaded areas may not fit properly if they are coated. Bearing surfaces with close tolerance cannot be coated. Some parts may require a bare spot for electrical-grounding contact. It is important to select a mask that is effective, easy to use and reasonable in cost.

Masking parts will add additional labor to the coating process. It is important to understand the different types of masks that can be used. Masking can be as simple as placing a plug in a single hole or it may require a specially made mask or fixture. One large hole in a large part will require very little labor while some smaller parts may have numerous spots that need masking and require a lot of labor. Selection of the right masking procedure will affect the cost of the part. The mask must be reasonable in cost and it must do an effective job of keeping the coating off the masked surface.

There are many commercially available masking materials for and powder coated parts. Tapes, plugs, caps and steel fixtures can be used. These cost and benefit issues are considered to determine the best possible way to mask a part:

- the cost per mask
- the number of times it can be reused
- the effectiveness of the mask
- the ease of application and removal
- ability to leave a clean parting line between the mask edge and the coating
- the need to be stripped and the frequency
- the temperature resistance of the mask material
- the ease of removal of adhesive backing

Tapes

A variety of different tapes are available for masking. They can be ordered cut in a particular pattern and size, in rolls of different sized discs, or in continuous rolls that can be cut to size. Different types of tapes are available for different applications.

There are many other tapes available including the ones listed in the chart below as well as 3M masking tape, high-temperature tape, polyethylene tape and others. Each tape has its own features and is suited to a particular task. Be sure to select a tape that has the properties that are needed for the process.

Temperature resistance and the nature of the adhesive backing are particularly important. The tape must be able to withstand the cure oven temperature and the adhesive should be easy to remove without extra effort or secondary operations. Polyester tape with silicone adhesive is commonly used for powder coating.

Selection of a particular tape may require some testing. Contact a supplier of tapes and get samples for trial. Balance the cost with the proper performance. Remember that the tape must stand up to the process (water, chemical, thermal, abrasion) it must be economical, it must be easy to apply and remove, it cannot leave adhesive on the part surface, and it must be within certain cost limitations.

Tapes are excellent for covering spots on parts that need to be free of powder coating. They can also cover holes or threads. Tapes are flexible and usually cost effective.

Table 10-1 - Masking Tapes

| Tape | Property | | | | | | |
|----------------|--------------------|---------------------|------------------|-----------------|------------------|--------|------------------------|
| | Max. temp. | Chemical resistance | Adhesive residue | Acid resistance | Blast resistance | Price | Suitability for powder |
| Polyester | 400 °F (204 °C) | fair | excellent | fair | fair | \$ | excellent |
| Glass cloth | 500 °F (260 °C) | excellent | fair | good | good | \$\$ | excellent |
| Aluminium foil | 300 °F (148 °C) | very good | fair | good | good | \$\$ | poor |
| Teflon | 400 °F (204 °C) | very good | good | good | good | \$\$\$ | good |
| Kapton™ | 500 °F (260 °C) | good | good | good | good | \$\$ | very good |

Plugs & Caps

Many different types of caps and plugs are used to cover threaded studs, bosses, and holes. The cost is reasonable and they can be re-used or left in place. They usually seal the masked area very effectively and they are less likely to “bridge” to the coating and create a rough parting line than a metal mask. There are many standard sizes available and they can also be custom made to fit a certain product.

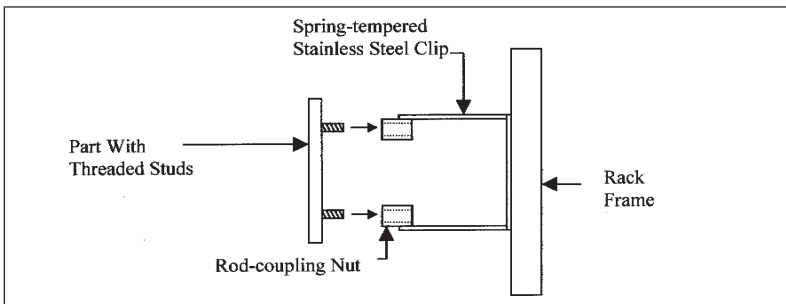
Specific sizes can be purchased at a reasonable cost in quantity. Sample kits with a variety of different plugs can be purchased to test different sizes and see what works best in a given situation. It is a good idea to have an assortment of sizes and styles around for product testing.

Caps and plugs are made of PVC, neoprene, silicone and other thermoplastic materials. The correct type for a specific masking job depends on the price and cure process. High temperature materials are required for powder coating operations. For example, silicone plugs may be capable of withstanding temperatures of 600 °F (315 °C). Neoprene is usually only good to temperatures of 275 °F to 350 °F (135 °C to 177 °C). Select a material that will meet all of the demands of the process for a fair price.

Masks Built into the Rack

In some cases, the best way to mask a part is by building the mask into the hanging fixture. A rack contact made with a piece rod can be fitted into a hole to mask the hole. A piece of tubing or a rod-coupling nut can be used to hold the part onto the rack and provide masking.

Figure 10-1 - Hanging Fixture Used to Mask Threaded Studs



The end of the part can be inserted into a pipe to keep the coating off the end.

The obvious advantage is that the labor of putting on and removing the mask is eliminated. The cost of the fixture is higher but it can be used indefinitely without replacement.

Throw Away Masks

In some cases, the mask can be used once and then thrown away. For example, one powder coater uses dixie cups to fill a hole in the center of the part. The dixie cup is inserted between the dry-off oven and the powder booth, the part is coated, and the cup is removed as the part exits the booth.

The cup keeps the powder from penetrating into the hole and then is thrown away. Any other type of mask would need to be high-temperature resistant and thus cost more. Also, when the mask is removed before curing, the edge line is clean. Removal of a mask after cure can cause a ragged parting line at the edge of the mask.

Other types of throw-away masks include Mylar stuffed into holes, corks, tooth picks, and paper. These masks are almost always removed prior to cure. This can be a low-cost and effective way to mask in some cases.

The Use of Air for Powder Removal

In some cases, air is used to remove the freshly applied powder coating material before it is cured. Low velocity air can be used to blow off a certain area or to vacuum powder from a surface. This eliminates the cost of masking materials and it provides a clean parting line at the coated edge.

Air blow-off or vacuum removal of powder requires precision design and execution for repeatable accuracy. It is not a good alternative where the number of holes or studs to be masked is so high that the operator will not be able to keep up. It may also require the operator to touch the part, possibly causing surface defects.

Machining After Coating

Some parts are difficult to mask and will require machining after they are coated. Machining the coating off of the part after coating is labor intensive but it does eliminate the cost of the mask and the labor to apply and remove it from the part. In some cases the machining operation is necessary anyway.

Parts that will be machined after coating should be sampled to make sure that the coating will not melt or otherwise break down at the edge of the machined area.

Summary

Masking is a very important step in the coating process. It is labor intensive and expensive. The type of masking material and its properties will be important to the effectiveness of the mask and its impact on production efficiency.

Keep in mind that any mask that is used must be efficient to apply and remove, it must be effective at keeping the coating from the target surface, it must stand up to the rigors of the process, and it must be cost effective.

5 Halos

A halo is a circular bare spot around the hook. Excessive halos are an indication of resistance near the hook point caused by poor ground. Hooks must be kept clean.

6 Seeds

Seeds are small particles of powder that have sintered or partially cured prior to application. This may have occurred during the manufacturing process or it may occur in storage. It may also be a small flake of impact fused powder. A test panel of each batch of powder will help identify the presence of seeds in the raw material. Inventory control is the key to stable powder in storage. Keep the material fresh by controlling heat and humidity and do not stack boxes more than 3 high. Impact fusion should be cleaned out of the system frequently.

Like any business, powder systems have fixed costs and variable costs associated with the operation. Fixed costs are payments on the building, staff and other expenses that stay the same regardless of what you do or how you do it.

Variable costs are the expenses that are directly related to the production of the finished product and they can be controlled to a certain extent. The ability of a business to make a profit is directly related to the efficient management of variable costs.

Purchasing the right equipment and operating it efficiently can minimize consumption of gas and electricity. To control utility expenses you must first understand how much it costs for fuel.

Most finishing systems use gas to heat the ovens and the washer. Some simple calculations can be used to determine consumption of energy to fuel the washer and ovens used in a powder coating system.

1 Gas Use in Btu's

Natural gas is the most common fuel used in powder coating systems as a heat source. It can be measured in British thermal units, therms, deca-therms, kilogram-calories and other units of measurement. The calculations in this manual are built upon English measure to yield answers in Btu's. Since the multipliers are based on Btu's, the formulas will not yield the correct answer if any of the factors is changed to metric measure. The conversions to another unit of measurement can be done by referencing the conversion tables at the beginning of the chapter.

Oven Energy Consumption

Energy consumption in an oven is primarily related to three areas; radiant loss through the oven panels, energy required to raise the product, racks and conveyor to temperature, and exhaust losses.

Panel Loss

To calculate the loss of Btu's through the oven panels, multiply the total square feet of oven panel x the panel loss factor (Table 11-1) x the temperature difference between the oven start-up and the controller setting.

| Panel Thickness | Loss Factor |
|------------------------|--------------------|
| 3" | .40 |
| 4" | .35 |
| 5" | .30 |
| 6" | .25 |
| 8" | .20 |

Table 11-1 - Panel Loss Factor

Formula: Sq. Ft. of Oven Surface x Panel Loss Factor x Temp. Rise

Example:

Oven Size: 20'0" W x 50'0" L x 10'0" H
 Operating Temperature: 300 °F
 Oven Start-up Temperature: 70 °F
 Panel Thickness: 4"

determine sq. ft of oven surface

sides: 10 x 50 = 500 x 2 sides = 1,000
 ends: 10 x 20 = 200 x 2 ends = 400
 top & bottom: 20 x 50 = 1,000 x 2 = 2,000
 add all surfaces: 1,000 + 400 + 2,000 = 3,400 sq.ft

find panel loss factor from table 11-1

(.35)

determine temp. rise in degrees F

300 - 70 = 230

calculate panel loss factor

3,400 ft² x .35 panel loss factor x 230 temp. rise = 273,700 Btu's

Product Loading

To calculate the Btu's required to maintain the set temperature in production, multiply the total load, (parts, rack, conveyor chain and trolleys), Table 11-2 x 0.12 (Btu's required per lb.°F) x temperature rise. The factor 0.12 is used for steel. Different materials will require a different multiplier. Table 11-3 shows the specific heat value for different metals.

| Chain Weight | | |
|---------------------|-----------------|-----------------------|
| Conveyor | per Foot | Trolley Weight |
| Enclosed Track | 3.50 lbs. | .5 lbs (H-Attach) |
| X348 | 2.14 lbs. | 2.34 lbs. |
| X458 | 3.14 lbs. | 5.18 lbs. |
| X678 | 6.39 lbs. | 16.50 lbs. |

Table 11-2 - Chain & Trolley Weights

| Metal | Specific Heat |
|--------------|----------------------|
| Steel | 0.120 |
| Aluminum | 0.226 |
| Iron | 0.175 |
| Zinc | 0.0931 |

Table 11-3 - Specific Heat of Different Metals

Example:

Chain - X348
 Trolley Centers 12"
 Racks - 5 lbs. on 12" centers
 Parts - 5 lbs. on 12" centers
 Line Speed - 10 FPM
 Oven Temp. - 300 °F
 Oven Start-up Temp. -70 °F

determine chain lbs./ft.

$$2.14 + 2.34 = 4.48 \text{ lbs./ft.}$$

determine part & rack load

$$5 + 5 = 10 \text{ lbs./ft.}$$

determine total load

$$4.48 \text{ lbs. chain \& trolleys} + 10 \text{ lbs. part \& racks} = 14.48 \text{ lbs./ft.}$$

determine total product load/min.

14.48 lbs./ft x 10 feet per minute = 144.8 lbs. per min.

determine product load/hour

144.8 lbs. per min. x 60 mins. = 8,688 lbs./hour

determine temp. rise

300 - 70 = 230

calculate Btu's

8,688 lbs./hr. x .12 Btu's x 2300 temp. rise = 239,789 Btu's

The parts that are processed may not be made of steel and may require a different factor from the list on page XI/3.

Exhaust Loss

The exhaust loss is determined by multiplying the cubic feet per minute of exhaust (CFM) x 60 minutes x 0.075 pounds per cubic foot x .24 Btu's per pound °F x Temp. rise.

Formula: CFM x 60 x 0.075 x 0.24 x Temp. Rise

Example:

| | |
|-------------------|-----------|
| Exhaust Volume: | 2,000 CFM |
| Set Temperature: | 300 °F |
| Oven Start Temp.: | 70 °F |

determine temp. rise

300 - 70 = 230

calculate exhaust loss

2,000 x 60 x .075 x .24 x 230 = 496,800 Btu's

- 0.075 is the density in lbs. of standard air
- 0.24 is the specific heat of air

To determine the total Btu's consumed, add a, b and c. In the above examples this total would be:

273,700 + 239,789 + 496,800 = 1,010,289 Btu's

To determine the actual cost, you must multiply the consumption by the cost for the energy used in the oven. Typical cost per unit of energy is shown in Table 11-3. Actual cost for energy varies widely in different regions.

| Fuel | Unit | Cost |
|-------------|----------------|-------------|
| Natural Gas | 100 cubic feet | \$ 0.45 |
| Propane | 1 gallon | 0.80 |
| | 100 cubic feet | 2.20 |
| Electricity | 1 kwh | 0.073 |

(Note: There is 36.39 cubic feet of propane per gallon at 60 °F.)
Table 11-4 shows the energy derived from various fuels.

Table 11-4 - Energy Costs

| | |
|--------------|--------------------------------|
| Natural Gas: | 100 Cubic Feet = 100,000 Btu's |
| Electricity: | 1 Kilowatt - hour = 3415 Btu's |
| Propane: | 100 Cubic Feet = 250,000 Btu's |

Table 11-5 - Energy in Btu's From Different Fuels

Using these tables, it is possible to calculate the comparative cost of different fuels.

Example: 2,000,000 Btu's required

$2,000,000 \text{ Btu's} / 100,000 \text{ (from table 11-4)} = 20$

$20 \times 0.45 \text{ (from table 11-3)} = \9.00

Natural Gas Cost: \$9.00 per hour

$2,000,000 \text{ BTU's} / 3415 \text{ (from table 11-4)} = 586$

$586 \times 0.073 \text{ (from table 11-3)} = \42.78

Electricity Cost: \$42.75 per hour

It is also possible to compare the changing of any one variable. For example, what happens if you use 6" of insulation instead of 4" in the oven panel loss example.

$3,400 \text{ ft}^2 \text{ oven panel} \times 0.25 \text{ (loss factor from table 11-1)} \times 230 \text{ (temperature rise)} = 195,500 \text{ Btu's loss with 6" panels}$
 $3,400 \times 0.35 \times 230 = 273,700 \text{ Btu's loss with the 4" panel}$
 $273,700 - 195,500 = 78,200 \text{ Btu's saved with 2" additional insulation}$

At \$0.45 per CCF of gas, this would mean a reduction in operating expense of \$0.35 per hour.

$78,200 \text{ } \div \text{ } 100,000 \text{ BTU's per CCF} = 0.782$
 $0.782 \times \$0.45 \text{ per CCF} = \$ 0.35/\text{hour savings.}$

What if the exhaust volume were reduced from 2,000 CFM to 1,500 CFM? Using the formula for exhaust losses:

$1,500 \times 60 \times 0.075 \times 0.24 \times 230 = 372,600 \text{ Btu's}$
 $496,800 \text{ Btu's at 2,000 CFM} - 372,600 \text{ Btu's at 1,500 CFM} =$
 $124,200 \text{ Btu's saved}$
 $124,200 \text{ } \div \text{ } 100,000 = 1.24$
 $1.24 \times .045 = \$ 0.56/\text{hour}$

With these formulas, the system operator can monitor the cost of drying and curing the product.

Washer Energy Consumption

Burner sizing to heat a washer stage may be based on tank sizing. The tank should be at least 3 times the size of the pump.

Tank Sizing Formula:

Tank Capacity in US gallons x 8.34 (lbs. per gallon) x Temp. Rise = Gross Btu's

Spray losses, or pump capacity determines the Btu's consumed in operation.

Pumping Capacity Formula: GPM x 8.34 x 60 Minutes x Delta T Factor

The GPM is determined by multiplying the number of nozzles times the capacity per nozzle. The term Delta T refers to a theoretical temperature loss factor from spraying. This factor can vary widely from 2 to 10. Table 11-6 shows the estimated temperature-drop chart for Delta T. The residual heat in the washer will often support more tem-

perature than what the chart indicates. Sometimes the burner will be too large as a result. A factor of 4 for each heated stage will usually produce reasonably accurate numbers.

| Operating Temperature °F | Temp. Drop Following First Stage | Temp. Drop in Intermediate Stages |
|---------------------------------|---|--|
| 70 - 100 | 4 | 2 |
| 101 - 120 | 5 | 3 |
| 121 - 130 | 6 | 4 |
| 131 - 140 | 7 | 5 |
| 141 - 150 | 8 | 6 |
| 151 - 160 | 8 | 6 |
| 161 - 170 | 9 | 7 |
| 171 - 180 | 10 | 8 |
| 181 - 190 | 11 | 9 |

Table 11-6 - Delta T

Example:

Number of Nozzles per riser: 5

Number of Risers: 10 pair

Total number of Nozzles: $5 \times 20 = 100$

Capacity of 50/50 flat spray nozzle at 20 PSI - 3.5 GPM

$3.5 \text{ GPM} \times 100 \text{ Nozzles} = 350 \text{ GPM}$

$350 \text{ GPM} \times 8.34 \text{ lbs./gal.} \times 60 \text{ minutes} \times 4 \text{ delta T} = 700,560 \text{ Btu's}$

Actual Btu's consumed in a washer can only be determined by the use of a gas meter, but these formulas create ranges for guidance and allow comparison if the variables change.

2 Electrical Consumption

Electrical motor power consumption can be estimated by using the table in appendix 1.

As an example, take a 10 horse power motor designed for 1800 RPM, at 460 volts. The full load amps (FLA) for that motor would be 12.6 (from motor chart).

To convert this to kilowatt hours (kwh), multiply the FLA times the motor Voltage to get watts and divide by 1,000 to get kilowatts.

$$12.6 \text{ FLA} \times 460 \text{ V} = 5796$$
$$5796 \text{ watts} \div 1000 = 5.8 \text{ kwh}$$

The cost per kwh from Table 11-3 is \$0.073. Therefore, the cost to run this motor at Full Load is \$0.42 per hour ($0.073 \times 5.8 = 0.42$).

These costs are based on the motor running at full load, which they rarely will do in production. Actual numbers can be determined by taking an amp draw from the motor and following the formula, substituting the actual amps for the FLA.

Some larger motors will need a power correction factor of 1.1 or 1.25, but the above formula will show the proper range. Also, variable speed motors will draw current at varying loads depending on the actual speed.

3 Compressed Air

Compressed air is used for fluidization of powder, transport from the collector to the feed hopper, for clean-up, for back-pulsing of cartridges and other uses within the powder application area. It is measured in volume as standard cubic feet per minute (SCFM) or cubic meters per minute (CMM) and in pressure as pounds per square inch (PSI) or kilograms per square centimeter. One SCFM of compressed air requires approximately 0.21 kwh to generate (One CMM requires 7.41 kwh). To determine the cost of compressed air:

volume of air x kwh per unit x cost per kwh = cost

For example, assume a cost per kwh of \$0.08 and a total CFM of 50.1

$50 \text{ CFM} \times .21 \text{ kwh/CFM} \times 0.08 = \$0.84/\text{hour}$

Spray equipment suppliers can provide the CFM needed to operate their equipment. For example, a typical powder gun may use a maximum of 6 CFM (0.17 CMM). A typical two-gun manual system may use around 40 to 50 CFM (1.13 to 1.42 CMM). A typical automatic

system with 8 automatic guns may use around 80 to 90 CFM (2.27 to 2.55 CMM). Output per gun, transfer efficiency, back-pulse frequency and color change frequency will affect these numbers.

Air compressors sizing should consider the maximum potential consumption of the system.

| | | | | | | | | | |
|----------------------------------|-----|-----|-----|------|-----|------|------|-----|------|
| Comp. HP | 3 | 5 | 7.5 | 10 | 15 | 20 | 25 | 30 | 50 |
| Max. CFM at 100 PSI | 12 | 20 | 30 | 40 | 60 | 80 | 100 | 120 | 200 |
| Max. CMM at 7 kg/Cm ² | .34 | .57 | .85 | 1.13 | 1.7 | 2.27 | 2.83 | 3.4 | 5.66 |

4 Cost Comparison of Two Coating Processes

The following tables show a comparison of annual operating costs between a liquid and a powder material. Actual costs of any material depend on the variables of price per unit, percent solids, transfer efficiency, material utilization labor, etc.

| Applied Material Cost | | | |
|------------------------------|---|---|---|
| Line | Variable | High Solids | Powder |
| 1 | Paint Cost | \$21/gal | \$3.00 |
| 2 | % Solids | 60% (reduced) | 98% |
| 3 | Specific Gravity | NA | 1.6 |
| 4 | Theoretical Coverage sq.ft./lb or gal. at 100% efficiency | line 2 x 1604 .60 x 1604 = 962 | 92.3/line 3 192.3/1.6 = 120 |
| 5 | % Mat. Utilization | 70% transfer eff. | 95% with reclaim |
| 6 | Film Thickness | 1.2 Mils | 1.5 Mils |
| 7 | Actual Coverage sq.ft./lb or gal. | line 4/line 6 x line 5 962/1.2 x .70 = 561 | line 4/line 6 x line 5 120/1.5 x .95 = 76 |
| 8 | Applied Cost \$/sq.ft. | line 1/line 7 21/561 = \$0.0374 sq.ft. | line 1/line 7 3/76 = \$0.0394 sq.ft. |

Note: The number 1604 is the thickness in mils of one gallon of water poured into a 1 foot square box. The number 192.3 converts the water to a dry equivalent by dividing 1604 by 8.34 (lbs. per gallon of water).

| Application System | Conventional Air Spray | Electrostatic Spray | Disk or Bell Spray |
|---------------------|------------------------|---------------------|--------------------|
| Transfer Efficiency | 40% | 50 - 70% | 80 - 90% |

Table 11-7 - Material Utilization

| Spray Booth Exhaust | | | |
|----------------------------|----------------------|--|----------|
| Line | Variable | High Solids | Powder |
| 9 | Booth Opening sq.ft. | 200 | 60 |
| 10 | Exhaust Volume CFM | line 9 x 120 200 x 120 = 24,000 | NA |
| 11 | Outside Air Temp. °F | 50 °F (from table 4) | 50 °F |
| 12 | Plant Air Temp. °F | 70 °F | 70 °F |
| 13 | Temp. Rise °F | 20 °F | 20 °F |
| 14 | BTU's Required | line 10 x line 13 x 1.1* 24,000 x 20 x 1.1 = 480,000 (Btu's at 100% efficiency) | 0 |

* The constant 1.1 is found by multiplying 0.018 (Btu's required to raise one cubic foot of air one degree F at 100% efficiency) by 60 (converting CFM to CFH). 1.08 is rounded to 1.1.

| Cure Oven Exhaust Loss | | | |
|-------------------------------|--------------------------------------|--|--|
| Line | Variable | High Solids | Powder |
| 15 | Production sq.ft./hr. | Parts Per Hr. x sq.ft./part 6,000 (as an example) | 6,000 |
| 16 | Coverage sq.ft./lb. or gal. | 561(from line 7) | 76 (from line 7) |
| 17 | Applied Coating lb. or gal. per Hour | line 15/line 16 6,000/561 = 10.7 gals. | line 15/line 16 6,000/76 = 79 lbs. |
| 18 | Solvent Load lbs. or gals per Hr. | (100% - line 2) x line 17 x line 3 100 - 60 = 40% .40 x 10.7 = 4.28 | (100% - line 2) x line 17 x line 3 100 - 98 = 2% .02 x 79 lbs. = 1.58 |
| 19 | Exhaust Required Cubic Feet/Min. | line 18 x 167(a below) 4.28 x 167 = 715 CFM | line 18 x 250(b below) 1.58 x 250 = 395 CFM |
| 20 | Cure Temp. °F | 325 °F | 375 °F |
| 21 | Plant Temp. °F | 70 °F | 70 °F |
| 22 | Temp. Difference °F | 255 °F | 305 °F |
| 23 | BTU's Required | line 19 x line 22 x 1.1 715 x 255 x 1.1= 200,558 Btu's | line 19x line 22x line 1.1 395 x 305 x 1.1= 132,523 Btu's |

(a) 167 = 10,000 SCF (NFPA Recommended) x 1 Hour/60 Min. Liquid

(b) 250 = 1,500 SCF (NFPA Recommended) x 1 Hour/60 Min. Powder

| Oven Panel Radiation, Conveyor, & Part Heat Loss | | | |
|---|---------------------------------|---|--|
| Line | Variable | High Solids | Powder |
| 24 | Temp. Diff. (line 22) | 255 °F | 305 °F |
| 25 | Conveyor & Tooling Load lbs./Hr | Conveyor + Rack lbs./ft x Line Speed (FPM) x 60 Min. 4.5 lbs +5 lbs. =9.5 lbs./ft. 9.5 x 10 FPM = 95 lbs./Min. 95 x 60 = 5,700 lbs. per Hr. | 5,700 |
| 26 | Product Load lbs./Hr. | line 15 x Product lbs./sq.ft. 6,000 x .5 = 3,000 lbs./Hr. | 3,000 |
| 27 | Total Load lbs./Hr. | line 25 + line 26 5,700 + 3,000 = 8,700 | 8,700 |
| 28 | Specific Heat Load | 0.125* (steel) | 0.125 |
| 29 | Total Load Loss BTUs | line 24 x line 27 x line 28 255 x 8,700 x .125 = 277,313 Btu's | line 24 x line 27 x line 28 305 x 8,700 x .125 = 331,688 Btu's |
| 30 | Radiation Loss | Total Oven Surface sq.ft. x Pan. Loss (Table 2) x line 24 5,000 sq.ft. x .30 x 255 = 382,500 Btu's | 5,000 sq.ft. x .30 x 305 = 457,500 Btu's |
| 31 | Total Heat Loss | line 29 + line 30 277,313 + 382,500 = 659,813 Btu's | line 29 + line 30 331,688 + 457,500 = 789,188 Btu's |

*Specific Heat Load: Steel-0.125, Iron-0.130, Aluminum-0.248

| Panel Thickness | Panel Loss Factor |
|------------------------|--------------------------|
| 3" | .40 |
| 4" | .35 |
| 5" | .30 |
| 6" | .25 |
| 8" | .20 |

Table 11-8 - Radiation Loss (Btu loss per sq.ft./hour)

5 Quoting a Part

To calculate the cost to coat a given part, all of the costs associated with the operation must be included. The following list of cost issues covers all of the different areas of a business. Begin by creating a short list of product variables.

List the :

Annual Volume

Set-up Volume for a typical run

Part Dimensions: coat 1 side or 2; total ft² per part

| Cost Summary: Annualized Dollars | | | |
|---|----------------------------|---|--|
| Line | Variable | High Solids | Powder |
| 46 | Material Cost | line 8 x line 15 x Op.Hrs./Yr. .0374 x 6,000 x 2,000 = \$448,800 | line 8 x line 15 x Op.Hrs./Yr. .0394 x 6,000 x 2,000 = \$472,800 |
| 47 | Energy Cost | line 37 x Op.Hrs./Yr. 6.10 x 2,000 = \$12,200 | line 37 x Op.Hrs./Yr. 4.19 x 2,000 = \$8,380 |
| 48 | Labor & Main. Cost | line 45 x Op.Hrs./Yr. 73.05 x 2,000 = \$146,100 | line 45 x Op.Hrs./Yr. 50.78 x 2,000 = \$101,560 |
| 49 | Total Operating Cost | line 46 + line 47 + line 48 448,800 +12,200 +146,100 \$607,100 | line 46 + line 47 + line48 472,800 +8,380 +101,560 \$582,740 |
| 50 | Annualized Cost per sq.ft. | line 49/ (line 15 x Op.Hrs./Yr) 607,100/(6,000 x 2,000) 607,100/12,000,000 = \$0.050 | line 49/ (line 15 x Op.Hrs./Yr.) 582,740/(6,000 x 2,000) 582,740/12,000,000 = \$0.048 |

Note: This example does not include electrical consumption or washer operating cost.

Material Cost

$$\frac{192.3 \times \text{mat. util. \%}}{\text{mils.} \times \text{s.g.}} = \text{ft}^2/\text{lb.}$$

Adjust the ft² for powder losses on the rack; assume a percent of the part ft².

For large parts the percent will be lower because there will be more part and less rack.

For smaller parts the percent will be higher. The percent could be as high as 100.

For material utilization assume 50% w/o reclaim and 90% with reclaim.

For mil thickness use a default of 3.

For s.g. use a default of 1.5.

$$\text{Cost of powder} \cdot \text{ft}^2/\text{lb} = \text{cost}/\text{ft}^2$$

$$\text{Cost}/\text{ft}^2 \times \text{ft}^2/\text{part} = \text{material cost}/\text{part}$$

Add Start up Waste (charging and purging the system) say 10 lbs.
(may vary with more or less guns)

Cost of lb of powder x 10 lbs. waste = total start up material cost

Start up material cost \div parts per typical run = cost per part of
waste add

Process Data

Design Rack – parts across x down

One or two sided?

Determine hook spacing on the conveyor

Determine line speed; faster for larger part, slower for smaller part;
may be different in production

Add a downtime fudge factor, say 20%

ft/hr. x pcs./ft. = pcs./hr. at 100%

factor in downtime percent

Labor

Determine people to output ratio

Include

- sprayers
- QC
- supervisors
- rackers (on-line and off-line)
- others (masking, blow-off, etc.)

Determine Straight Wage

Average Wage/hr. x no. people = total straight wage

Total straight wage \div pcs. per hour = \$/part

Burden

Variable Labor – additions to hourly wage as a percent; insurance,
uniforms, training, taxes, etc. – say 25%

Total direct labor x addition % = addition to labor cost

Variable Line Burden - Utilities, Packaging, Supplies; say \$75.00/
hour as an example

XI

To determine an accurate number for a specific line, collect data for the monthly cost.

monthly cost \div hours of operation per month = hourly cost
hourly cost pcs./hr. = cost per part

Fixed Cost

Building Rent, Debt, Administration, Maintenance; say \$400.00/hour as an example

To determine an accurate number for a specific line, collect data for the monthly total cost.

total fixed cost \div pcs./hr. = cost per piece

Scrap Cost

determine scrap as a percent; say 5%, add cost of rework (per piece cost x no. pcs. \div run = scrap cost

determine the percent that cannot be salvaged; say 1 of 5 (20% of scrap percent), add the cost to buy a part

determine total scrap cost

Add Cost

Material cost

Labor cost

Burden

Fixed cost

Add Profit – 20 to 40% (build a table to show results with different margins)

6 Return on Investment (ROI)

Calculation of return on investment requires some idea of annual volume. This can be determined by how much product can be put through the system based on the size of the product opening and the line speed. If the line is run at full capacity, the work envelope will be about 50% full for about 80% of the available hours.