

# THE DEVELOPMENT AND DIFFUSION OF POWDER COATINGS IN THE US AND EUROPE

TECHNICAL APPENDIX

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# TECHNICAL APPENDIX

*Please note: This technical appendix covers additional detail about the powder coating manufacturing, powder coating chemistries, and application methods not covered in the main text. This material is directly taken from Akzo Nobel's "Complete Guide to Powder Coating" (1999) unless otherwise noted.*

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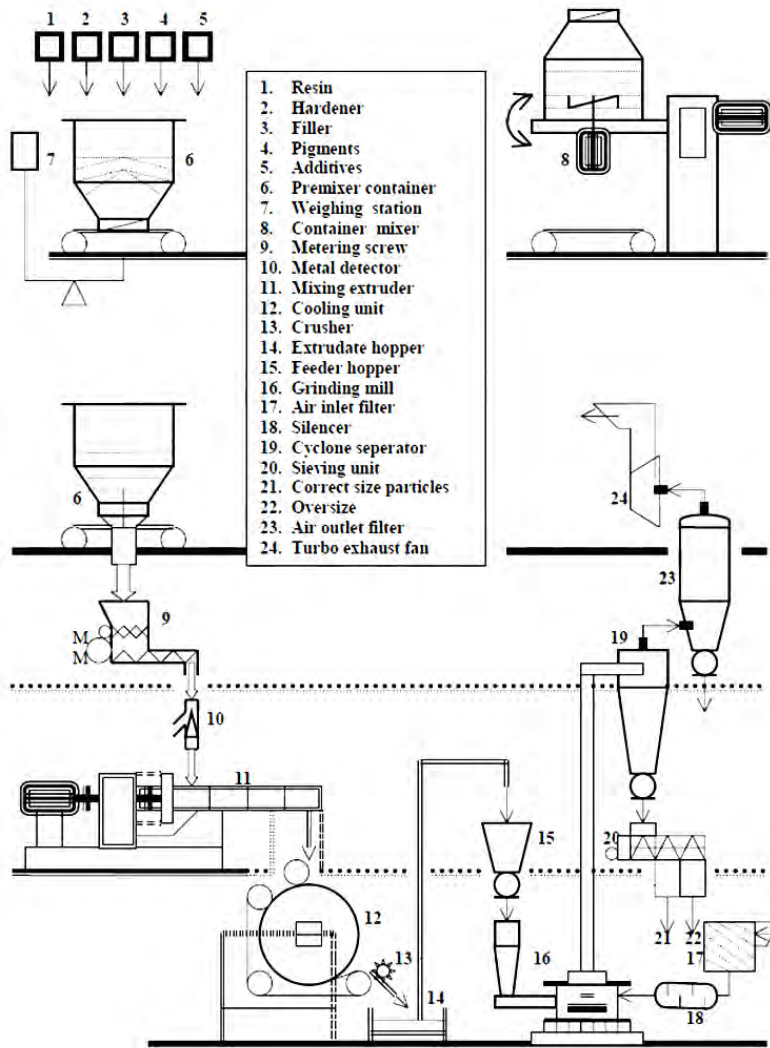
# 1. Powder Coating Manufacturing

This section describes the manufacturing and quality control process for powder coating materials. Producing industrial powder coatings consists of several distinct stages, namely:

- Weighing, premixing and size reduction of raw materials
- Extrusion of pre-mix, cooling and crushing of the extrudate into chips
- Micronising the chips into the final powder
- Post mixing, packaging and storage.

At each stage of the production process the quality must be checked because once the powder coating material has been produced, it cannot be changed or adjusted in any significant way. The formulation and the manufacturing conditions are therefore critical. Reworking of an 'out of specification' product is difficult and costly. (See Figure A-1 for a simplified flow sheet of the powder coating material production process).

**Figure A- 1: Powder Coating production process**



## **Weighing, premixing and size reduction of raw materials**

Raw materials typically consist of resin, curing agents, pigments, extenders and additives such as flow and degassing aids. Each raw material must pass their individually pre-set quality controls. Each component is then weighed with the necessary degree of accuracy (which may be to the nearest ten thousandths of a gram). All pre-weighed components are placed in a mixing container according to the formulation. The container is then attached to the mixing drive and the raw materials are thoroughly mixed by the specially designed pre-mixer cutting blades for a pre-set period of time. The raw materials can also be reduced in size to improve the melt mixing later in the process.

### **Quality control**

A final sample of the raw material pre-mix is checked for conformity and processed through a small laboratory extruder and grinder. The resulting powder is then applied onto a test panel, cured in the oven and subjected to various tests:

- Color, surface flow and gloss
- Mechanical performance (including curing)
- Gel time.

If adjustments are required both the mixing process and quality control procedures are repeated until the powder achieves the specification. No further modification to the powder can be made after this stage in production.

### **Extrusion of the premix**

The mix is fed into the dosing system of the extruder. The extruder barrel is maintained at a predetermined temperature (between 70 & 120°C, depending on the product type). The barrel temperature is set so that the resin is only just liquefied and its contents are mixed using the screw in the barrel. Consequently, the individual ingredients are dispersed and wetted by the resin, which produces a homogeneous composite. The feed rate of the dosing equipment and the speed of the extruder screw are balanced to ensure that the screw is kept loaded within the extruder barrel. The conditions of high shear and intimate mixing are maintained within the extruder by precise adjustments of these three parameters. The molten mass produced in the extruder barrel is forced to cool down via a cooling-transporting device. The solidified material is then broken up and reduced in size through a crusher into workable chips of 5 to 10mm in size.

### **Quality Control**

At this stage in the process the product quality is tested using a sample of the chips. The laboratory grinds the chips to a powder and prepares a test panel using the material. The intermediate product is then checked for quality against the following criteria:

- Color, gloss, appearance and flow
- Mechanical and reactive properties
- Application.

Too high a temperature in the extruder barrel will not only result in a low melt viscosity, low shear forces and poor pigment dispersion, but will also in turn produce a low gloss coating. The resin and hardener in the premix may also start to react in the extruder, which will also have a detrimental effect on the product performance. It is not possible to make changes to the formulation at this stage in the production process. It is also easier to handle the extruded chip as a re-work raw material if manufactured 'out of specification' than once the powder has been micronised.

### **Micronising of the chip into the final powder**

The chips are ground to the required particle size in a grinding mill. The chips are fed onto an enclosed grinding wheel with stainless steel pins, which breaks the chips down creating a powder. The powder is carried through a classifier into a cyclone collection system via a regulated air flow. In order to achieve the optimal particle size distribution (psd) further treatment may be needed which can consist of cycloning, classifying, filtering or sieving. In modern plants the rejected oversize from the sieving operation is automatically fed back into the feedstream of the micronising mill. The typical particle size range for electrostatic application methods should be within 10 to 100 microns. Deviation from this psd can result in poor performance and appearance of the powder.

### **Quality Control**

The final powder coating is as rigorously quality control tested as the extrudate to ensure it meets the specification of the customer or market. As the particle size distribution is a critical factor in the successful use of the powder the particles are analyzed for their precise particle size distribution.

### **Post mixing, packaging and storage**

In order to meet the customer specification or special conditions of use additives may have to be mixed through the final product. Powder packaging is provided in:

- carton boxes - up to 25kg
- bags - 400 to 900 kg
- metal/plastic containers (Durabins)

The powder can be safely stored if kept in its unopened packaging in a dry, cool place (30°C) for up to 12 months. Higher temperatures and longer storage periods will result in absorption of moisture. Storage conditions can vary for some powders so the product data sheet should be referred to at all times.

### **Quality Control**

It is advisable to check the powder after 6 months of storage to ensure no quality problems have occurred.

## 2. Powder Coating Chemistries

Two major types of powder coatings exist: thermoplastics (~10% of powder coatings) and thermosetting powders (~90% of powder coatings).

Thermoplastic coatings do not chemically react upon temperature increase, but they melt and flow out onto the substrate. Application is usually in the industrial market coating wire, pipes and accessories. The thickness of these coating films is typically around 10 mils (250 microns) or more.

Thermosetting coatings also melt upon temperature increase, but undergo a simultaneous chemical reaction and polymerize through cross-linking into a resistant film. Once this chemical reaction has occurred the powder coating film cannot melt again. These coatings are used in both the decorative and the industrial markets.

Thermosetting powder coatings consist of:

- resins,
  - curing agents,
  - pigments,
  - extenders and additives.
- *Resins*: the selection of the correct grade of resin or blend of resins is very important, as these form the basic properties of the powder coating material and also control the film properties such as melting point, flow and leveling. Relatively low molecular weight resin, as solid grades, have a softening point between 60°C & 110°C. Low melting points can result in a tendency for powder to 'cake' during storage. They also have an extreme degree of flow on curing where a low degree of 'sharp edge coverage' is obtained due to the coating flowing away from the edges. Usual resins include epoxies, polyurethane, polyester and acrylics (see below for additional information about the properties of these different resins).
  - *Curing Agent* (also known as hardener): the hardener is used to cross-link the resin at a given temperature. The degree of cross-linking can also be used to determine the gloss level, degree of surface 'orange peel' and other aspects including structure and texture effects. The curing agent should be nonreactive at room temperature, remaining latent up to 100°C and should react fully between 100°C & 180°C. This reaction should not be so rapid as to prevent complete flow out of the fused resin and not so slow that it creates commercial implications. Usual crosslinkers are amines, anhydrides and blocked isocyanates. Catalysts are used to accelerate the curing speed.
  - *Pigments and extenders*: pigments must be inert, enduring to light exposure, and heat resistant. As with most coatings they are used to create a decorative effect.
    - Titanium dioxide creates white, pastel and light tints
    - Carbon black creates blacks and grays
    - Phthalocyanine creates blues and greens
    - Aluminium and bronze creates metallic effects.

Organic pigments have to be handled with care as some of them can react during processing and curing. This can result in loss of brightness and cleanliness and in these cases alternative pigmentation has to be used. Certain inorganic extenders can be incorporated into the formulations without reducing the film quality. Usually extenders are of high specific gravity and although they reduce the raw material cost they can adversely affect the area covered by the powder.

- *Additives*: even after the optimum resin, hardener and pigments have been selected, adjustments to the formulation may still be required to modify flow and film properties to suit the application and curing conditions (i.e. Thixotropic agents to slow down the flow and UV stabilizers). Other functions of additives are:
  - Increase/decrease electrostatic attraction
  - Increase/decrease surface leveling
  - Creation of decorative effects
  - Decrease stoving temperature requirement
  - Changing conductivity
  - Increase re-coatability
  - Increase surface hardness.

**Thermosetting powder coating types.** Five major types of thermosetting powder coatings exist:

### **Epoxy**

The key strengths of epoxies are chemical and corrosion resistance coupled with strong mechanical properties but are not very UV tolerant. Therefore they are mainly used for engineering applications such as brakes, pipes, and electrical motors that come into contact with lubricants and oils. They were developed in late 1950 (Shell), diffused in 1960s and 1970s by Scado, Bayer, Cargill, Huls, and Coleanese (US)

### **Polyester**

Polyester powders are among the most commonly used in the industry. Thanks to their overall strong performance profile and in particular their excellent UV resistance they are the designated technology for exterior applications in the architectural market and the like. TGIC and TGIC-free formulations exist. In Europe TGIC is being phased out due to the increased risks of handling TGIC. Some companies like Dow and Akzo Nobel no longer develop new products containing TGIC. Polyester powders were developed in 1960d, standardized and diffused in 1970s (especially in Europe, in US only after 1981).



## Hybrid (Polyester/Epoxy)

These powders are most commonly used for interior design objects such as furniture and point-of-sales displays as well as white goods and appliances. The hybrid blends the advantageous characteristics of both polyesters and epoxies with the exception of UV resistance so they should be used for interior applications. Developed early 1970, standardized and diffused during 1970s. These powders make-up the majority of sales in the world.

## Polyurethane (IPDI)

The polyurethane technology is used for very specific applications requiring very high chemical resistance and corrosion resistance. In addition the polyurethane coating gives a particularly hard surface film. These powders were developed in the early 1970s, and standardized and diffused throughout the 1970s (especially in the US).

## Acrylic

Acrylic powders give very high gloss finishes with excellent chemical and corrosion resistance. For these qualities they are used in many areas of automobile production such as wheels and clear top coats for cars. The acrylic technology is not compatible with other powder technologies and should therefore be applied in especially dedicated lines to avoid contamination. Developed in the early 1970s, and standardized and diffused during the 1970s in Europe by Bayer.

These five families of thermosetting powder coatings exhibit varying levels of performance in specific properties. Common desirable properties in powder coatings are weatherability, corrosion resistance, chemical resistance, heat resistance, impact resistance, hardness, flexibility, and adhesion. A comparison of how the major types of thermosetting powder coatings perform on these properties is listed in Table A-1.

**Table A- 1: Properties of Thermosetting Powder Coatings**

Property	Properties of Thermosetting Powder Coatings				
	Epoxy	Acrylic	Polyester	Hybrid	Polyurethane
Weatherability	Poor	Excellent	Excellent	Fair-Poor	Good
Corrosion Resistance	Excellent	Good	Very Good	Excellent - Very Good	Very Good
Chemical Resistance	Excellent	Very good	Very Good - Good	Very Good	Very Good
Heat Resistance	Very Good	Good	Good	Very Good - Good	Very Good
Impact Resistance	Excellent - Very Good	Good-Fair	Good	Very Good	Very Good
Hardness	HB-5H	HB-4H	HB-4H	HB-2H	HB-3H
Flexibility	Excellent - Very Good	Good-Fair	Very Good	Very Good	Very Good
Adhesion	Excellent	Good-Fair	Excellent	Excellent	Very Good



**Table A-2: Powder coating applications**

Product categories	Sub-category	Description	epoxy	hybrid	polyester (TGIC or TGIC-free)	poly urethane	acrylic
<b>appliance</b>	household (indoor)	coolers, freezers, washer/dryers, microwaves, air conditioners, small appliances		v			
	household (outdoor)	lawn mowers, tractors, hand & garden tools			v	v	v
	HVAC	Outdoor and indoor systems (heaters, radiators)		v	v		
	House wares	Pots, pans, tea kettles				v	
<b>architectural</b>	building elements	windows, door frames, paneling		v	v		
	pipes and valves	internal and external metal pipes needing anti-corrosion, pumps	v				
	structural elements	girders, pillars and frames			v		
<b>automotive</b>	bodies	topcoating					v
		undercoating		v	v		
		body shell		v			
		underbody, underhood	v	v			
	components	exterior trim			v	v	
		motor blocks, bumpers, mirrors		v			
		interior trim	v	v	v		
		alloy wheels		v	v		v
		truck primers/surfacers		v	v	v	
<b>electrical</b>	electronic	decorative outer surfaces		v	v		
	fixtures, enclosures	lamp fixtures and housings, enclosure cabinets, electrical components	v	v	v	v	
	IT products	PC, server, printers, copiers		v			
<b>furniture</b>	indoor	office (desks, filing cabinets, book cases); household (tables, beds)		v			
	outdoor	lawn&garden furniture			v	v	
<b>industrial machinery</b>	agricultural	tractors, plows	v	v	v	v	v
	construction	construction equipment	v	v	v	v	v
	power applications	fan, electrical motors, pumps	v				
<b>marine</b>	components	Broad range from engine components and deck hardware to railings and swim platforms	v	v	v	v	v

Source: summarized by CGGC from industry sources

### 3. Powder Coating Application

The application of powder coatings consists of three major steps: pretreatment, application, and curing. This section of the report provides information on these three stages.

#### Pre-treatment

The selection and intensity of surface preparation is closely related to the original state and nature of the substrate, the type of contamination and the desired result of the final product. It is essential to undertake a process of pretreatment of the surfaces to be coated prior to the actual powder application in order to achieve the full potential of the selected powder coating materials. The objectives of pretreatment of metal surfaces are:

- Removal of impurities, including soil, welding splatter, scale, grease, oil etc
- Conditioning of the surface for optimum adhesion of the coating film
- Obtaining uniformity throughout the entire treated surface of the substrate.

These objectives can generally be achieved when a well selected pretreatment process has been carried out. Not all of these methods work on all surfaces. The pretreatment will vary depending on the required final use of the substrate. A complete pretreatment process will consist of:

- Cleaning
- Rinsing
- Conversion coating
- Seal rinsing
- Drying
- Cooling.

#### Cleaning

Cleaning is the removal of all organic and inorganic contamination on the surface of the metal substrate to be coated. In the usual aqueous cleaning system surfactants play an important role in the process such as wetting, emulsifying, neutralizing and dissolving etc. The first step is usually the removal of oil and grease by either detergent, solvent, emulsion or alkali cleaners. The cleaning operation can be undertaken by immersion or spray processes, in both cases, usually involving a number of tanks in sequence. The selection of the correct method depends not only on the nature and degree of contamination, but also upon the scale of operation and required result. An additional acid cleaning step may be necessary when rust and scale needs to be removed.

Cleaning methods consist of either chemical or mechanical preparation. Mechanical preparation can be performed by sandblasting or other means of cleaning the part. In most instances, the metals delivered from the supplier are usually of such quality that additional mechanical preparation can be omitted and the cleaning process consists of just chemical treatment. The most common substrate for electrostatically applied powder coatings

material is metal. Specific cleaning methods are appropriate for different substrates, such as steel, aluminum and zinc substrates such as galvanized steel.

### **Rinsing**

High quality water rinsing of the surfaces is necessary. The objective of rinsing is to flush away the remaining 'drag-out' from the previous bath and to neutralize the surface. It must be ensured that the cleaned and dried substrate is not contaminated with alkali, acid or any other components. The critical factors in undertaking a high quality rinsing process are:

- Quality of fresh water
- Quantity of the water contacting the substrate
- Duration of water contact
- Rinsing method (immersion or spray)
- Object configuration.

The volume and quality of this rinse water is of great importance to the quality of final rinsed substrate surface. The substrate cannot be any cleaner than the water used for rinsing! The water volume and quality needs to be maintained at certain levels to ensure that rinsing is at its optimum performance. Monitoring the cleanliness of the water by measuring the total dissolved solids (tds) and alkalinity (pH) with reliable, automatic devices is an effective control. A proven concept for optimum use of water is the 'back-flow system' where fresh water enters at the last stage of rinsing and flows counter-current to the parts which are already treated. Water with a hardness higher than 250ppm CaCO<sub>3</sub> and combined chlorides and sulphates higher than 100ppm should not be used. De-ionized water is often drawn from, and recycled to, a separate installation.

### **Conversion Coating**

Once all impurities on the metal surface have been removed the surface is ready to be conditioned for optimal adhesion of the coating film. In powder coating, the most common application for extended corrosion resistance relies on conversion coating. The different methods available are iron, zinc and chromium phosphating. Selection depends on the substrate and the ultimate requirements, for example which particular market is being served and which specification is required to be met. Because of environmental issues, the trend in certain countries is to consider the elimination of heavy metal containing conversion coatings or to convert from zinc to iron or from chrome to non-chrome. It is important that the finisher checks to see whether such substitution is allowed by their customer's specification. With any performance specification of 200-800 hours salt spray and a well designed 5 or 6 stage pre-treatment system with good cleaning and rinsing, there would not be any need for zinc or chrome based conversion coatings. In such cases, iron phosphate will be adequate, provided a powder coating is applied which is designed for the required corrosion resistance. When the clean metal comes into contact with the slightly acidic phosphating solution, pickling starts, iron is dissolved, hydrogen is liberated and the phosphate coating is deposited. The purpose of the phosphate coating is to bond the

powder coating film to the metal surface. As such, it should provide a uniform, tightly bonded phosphate throughout the entire treated surface of the substrate resulting in the absence of flash rust, powdering and windowing. The greater the weight of the phosphate coating, the higher the corrosion resistance is created and the lower the coating weight, the better the mechanical properties. It is often necessary to select a compromise between corrosion resistance and mechanical properties. Experience has shown that a fine grain iron-phosphate is recommended with coating weights of 300-900 mg/m<sup>2</sup>.

#### *Seal Rinse*

The purpose of a seal rinse is to provide a final passivation. Non-reacted chemicals and other contaminants are removed, any bare spots in the coating are covered and the metal surface is prevented from flash rusting. A dilute solution of low electrolyte concentration is used. Instead of the conventional chromium compounds, sealers are applied which are not based on chromium - these are more environmentally friendly.

### **Drying and Cooling**

After the final rinsing and before any parts are powder coated, the parts must be completely dry and cool. Two methods used for this type of drying are the blow-off method and the dry-off oven. One problem that occasionally occurs is that parts are insufficiently drained. This can normally be resolved by altering the hanging method or drilling a drain hole. In certain cases a blow-off system will be inevitable. Dry-off ovens should heat the parts to be coated sufficiently to evaporate the surface water. Convection ovens and infra-red radiation ovens are both used for this purpose. It is important that the parts are cooled prior to entering the powder spray booth, otherwise the powder can start to melt on the surface of the coated part and then the performance of the powder coating film may be adversely affected.

### **Waste Treatment**

Draining some of the rinsing solutions or sludge from the reservoirs will occur as a result of the pretreatment process. The chromate and zinc phosphate baths are seldom dumped. However, when they are, the solutions have to be treated and the local national and/or regional environmental laws and regulations must be followed and adhered to strictly. The iron phosphate solutions are easier to dispose of because they operate in the pH range of 4-6. Local authorities may allow the industrial user to raise the pH to 6-9 and dispose of it into the local drainage system.

### **Powder Application**

Powder application - For most coating requirements powder is sprayed and charged electrostatically through spray guns onto the work piece. Other methods include fluidized bed dipping, powder cloud and electrostatic brush application. Most of the methods used fall into one of the following processes:

1. Electrostatic spray process:

- a. Corona spray gun
  - b. Tribo spray gun
2. Fluidized bed process.

The advantages and disadvantages of the electrostatic spraying process and fluidized bed process are compared below. In most cases, however, the electrostatic spray process is more flexible and versatile.

## **Electrostatic Powder Spraying**

### **Advantages**

- Difficult shapes can be coated
- Film thickness between 30-250
- Simple and low cost for automation
- Color can be changed relatively simply
- No pre-heating of components required

### **Disadvantage**

- Cost of equipment is higher than a fluidized bed.

Electrostatic spraying, which is the most widely applied coating method, is not only more versatile, but generally provides better control of the powder coating properties. The electrostatic spray process makes use of electrically charging the powder particles. The powder is contained in a hopper in a fluidized state and is held adjacent to the application booth. It is delivered by a powder pump and a transport air flow system to the electrostatic spray gun. The particles are charged on emission from the gun and with the help of the transport air move in the direction of the grounded work-piece. As the charged particles come close to the grounded work piece, electrostatic attraction causes the particles to deposit and adhere to the work piece. This process is shown in Figures 8a and 8b in a simplified form.

There are two distinct methods for building up the charge on the particle surfaces, Corona and Tribo spraying. The Corona charging method makes use of a high voltage generator (80-100 kv) to bring an electrostatic charge (mostly negative) onto the powder particles through the intermediate process of creating oxygen ions. In the Tribo method the electrostatic charge (positive particles) is built up by the particles rubbing with increased velocity along a specially selected material (e.g. teflon) inside the spray gun for sufficient time, without the use of a high voltage generator. Both spraying methods have their own typical powder cloud build up. Details follow:

### *Corona Charging*

#### **Advantages**

- Strong electrostatic field results in effective charging and higher deposition
- Electrostatic field lines support the powder particles to move towards the work-piece
- Simple repairs of the powdered surface are possible

Light, robust spray gun  
Accepts different types of powder materials and particle sizes  
Film thickness can be simply changed by voltage variations  
Simple construction is suited for fast color changes.

#### Disadvantages

Redundant ions generate a self-limiting effect  
Strong field lines lead to Faraday effect (irregular coating, corners and crevices are not properly covered)  
These effects can be reduced or eliminated respectively by voltage changes or use of anti-ionization rings (to reduce Faraday and Orange peel effect).

#### *Tribo Spray*

##### Advantages

No Faraday effect; deep crevices, corners and hollow spaces can be better penetrated  
Powder can be better directed by the use of directional finger sprayers and aerodynamics  
Less, if any, fatty edges on the coated surface  
Uniform coating  
Very good automation possibilities  
Higher charging effect without high voltage generator  
Higher deposition effect  
Higher productivity by closer arrangement of objects  
More optimal film thickness build-up  
Better flow; practically no orange peel effect  
Reduced risk for back-ionization  
Lower powder consumption

##### Disadvantages

Performance is strongly influenced by uncontrolled air-streams  
Special powder is necessary; formulation must be adapted to the Tribo charging process  
Particles smaller than 10 microns are difficult to charge  
Charging of particles takes more time and efficiency reduces during long runs  
Color changes take a long time  
Higher investment cost for equal capacity output  
Shorter life span of gun because of more wear on the internal components such as powder pump venturi inserts  
More precise specifications for the cleanliness and humidity of the compressed air  
Comprehensive training of the application personnel is recommended.

*Note: Industries using the tribo method of application are usually in Northern Europe where the humidity is more constant and the temperature lower in summer months.*

## Fluidized Bed Process

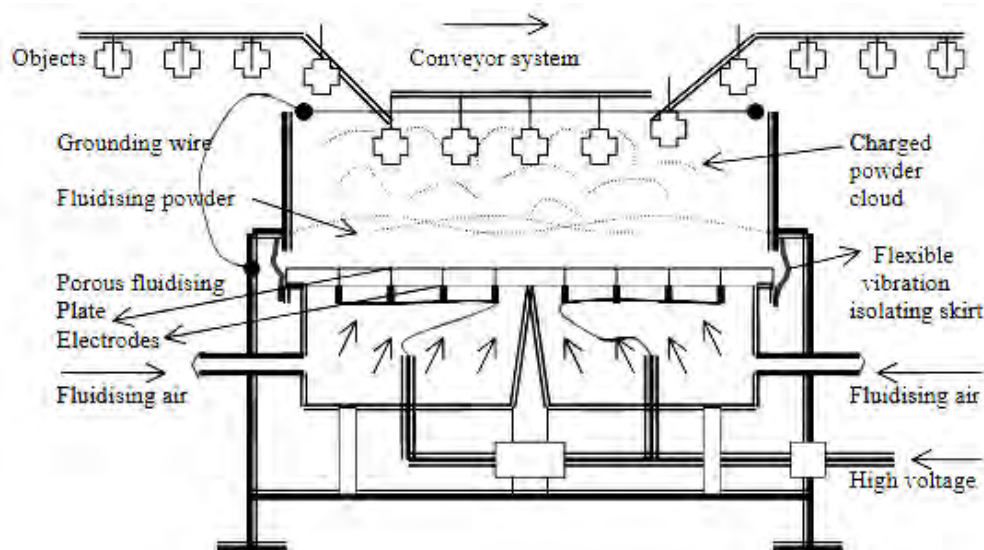
### Advantages

- Very high film thickness ( $>250\mu$ ) can be applied in one application and curing cycle
- Uniform film thickness can be achieved
- Low initial plant cost and maintenance.

### Disadvantages

- Relatively large volumes of powder are required to charge the plant
- The work-piece must be pre-heated and in some cases post cured in order to obtain the required result
- This application can only be used where relatively thick films are required
- The components should be of simple shape
- Thin gauge material cannot be coated by this method due to its low heat capacity
- A film thickness of between 200-250 microns is average
- Color change is a massive undertaking.

Figure A- 2: The fluidized bed system



Although the electrostatic spray method is the primary process for powder application, the fluidized bed coating method as one of the alternative coating processes. In the case of thermosetting powders, this is almost exclusively carried out with epoxy resin based powders for large work-pieces such as pipe line valves, fence posts etc. or small articles from the electronic industry for insulation. The majority of fluid bed coating is used for thermoplastic application. These coatings usually provide a thick tough coating film with excellent corrosion resistance and very good mechanical, electrical insulation and chemical properties.



Fluid bed coating does not need electrostatic charging of the powder particles and can take place with either pre or post-heated objects. When electrostatic charging a fluid bed, safety measures should be taken to avoid risk of explosion. The fluid bed is usually constructed as a container, the bottom part of which is an air plenum chamber and the top part is a porous plate. The area above the plate is filled with a certain volume of powder, which is fluidized by air from below. The resulting electrically charged cloud of powder is attracted to and deposits on an object when it is hung in the powder cloud.

### **Powder spray booth**

The powder that is not deposited onto the objects in the spray booth (overspray) is not wasted. It is recovered and re-used in the process. A spray booth should ensure that the overspray powder is contained, transferred and collected efficiently for recycling into the feed system. As such, the combination of these procedures ensures the optimum efficiency of the entire powder application operation. This recovery process is driven by an exhaust air ventilator that provides an airstream powerful enough to flow through the related extractor equipment such as a cyclone and filters. The air in the spray booth where the powder cloud is built up and moving should ideally be static. The electrostatic forces related to the powder particles, combined with the projection velocity of the particles leaving the spray gun (up to 60 m/sec), will perform a controlled movement of particles towards the object to be coated. This ideal situation cannot be maintained for three reasons: 1) the recovery need (discussed below); 2) spraying of powder is carried out and supported by a compressed air flow. This airflow must be removed by the exhaust ventilator; 3) the need to maintain a negative pressure in the spray booth to prevent the powder from escaping through openings of the booth into the working environment. Therefore negative pressure is maintained and air is allowed to enter the booth through the booth openings and this air has to be exhausted as an additional volume as well.

Carefully controlled air movements and a clear compromise in the operating conditions in and around the spray booth and the recovery system have to be decided. In critical areas inside the spray booth an air velocity is maintained of 0.4 to 0.5 m/sec which is low enough not to interfere with the projection velocity of the particle leaving the spray gun. For safety reasons a maximum of 10g/m<sup>3</sup> of powder in the air is required and legally accepted to avoid risk of explosion.

### **Powder recovery**

In both electrostatic spray processes there is the possibility to recover and re-use the powder that is not deposited on the object. The level of resourced powder in the system will be affected by transfer efficiency. Transfer Efficiency is the weight of powder transferred to the work piece from the total weight of powder that is passed through the powder spray gun in the same period expressed as a ratio. The function of a powder recovery system is to collect the overspray material and render it suitable for recycling and at the same time to remove the powder particles from the exhaust air stream before discharge into the

atmosphere. There are two types of collectors: Cyclone collectors and Cartridge collectors (there are more designs of collection systems which use these two principles).

### *Cyclone collectors*

The input to the cyclone is connected to the booth while the output is connected to a suitable exhaust fan. The overspray powder arrives at the cyclone inlet at a velocity of about 20 meters per second. On entering the cyclone chamber tangentially the air/powder mixture is given a rotary motion which creates a centrifugal force on the particles. The larger and heavier particles tend to be ejected to the outside walls of the chamber and fall to the bottom where they are collected. The lighter fractions will stay suspended in the air stream which on reaching the bottom is deflected by a conical tail air/powder mix into a rising spiral which is then carried through the central stack to a filter collector. For a standard powder the recovery efficiency can be as high as 95%. For lines that have a high % of particles <10 $\mu$  in the recovered powder the recovery efficiency will be reduced (as low as 85%). Inevitably therefore a cartridge filter is used in conjunction with a cyclone solely to prevent discharge of the fine powder to the atmosphere.

An additional advantage of cyclone recovery, with particular reference to colour change, is that due to frictional contact of powder particles, one with another and 'bounce-back', little or no adherence of powder particles occurs on the cyclone wall. This means that in many cases only the powder collection hopper need be thoroughly cleaned between colour changes. In many cyclones cones are removable and substitutes can be made as required if spares are held in stock. The contaminated cone can then be cleaned while the replacement is in operation. The recovered powder is removed from the cyclone by means of a rotary valve and is then passed through a sieve to remove any agglomerates and foreign matter. The recovered powder is then blended with the virgin material in predetermined proportions.

The virgin/reclaim mix ratio should always favor virgin. As cyclone efficiency depends on maintaining a high particle size velocity through the cyclone, the cartridge filter following the cyclone must be designed to maintain the stability of the required velocity throughout the system. The filter media should permit easy and frequent cleaning. The fabric filters which historically were used collected powder on the inside of the bag which does not fit with high production requirements as the bags have to be periodically cleaned down. A superior method is to arrange a series of cartridge filters within a metal enclosure so that the powder collects on the outside of the filters and are then cleaned by a reverse compressed air flow which operates about every 30 seconds to provide an air counter current to the powder air flow. The total resistance of this multi cartridge system can be balanced with that of the cyclone so that the cyclone efficiency can be maintained.

### *Cartridge filters*

In this technique the overspray powder from the application booth arrives at an enclosure containing a number of cartridge filters. Typical filter materials: Paper cartridges Scinter lamellar (plastic) Polyester cloth. The cartridge filters separate the powder from air by causing the powder/air mix to pass from the outside of the cartridge to the inside through a layer of filter material which retains the powder and allows the air to permeate through and on to the atmosphere. As filtering continues the retained powder accumulates on the upstream side of the cartridge and forms a powder layer which, being permeable to air flow, increases filtration efficiency albeit at the expense of increased resistance to air flow. This powder layer must be continuously removed to control filter resistance. The retained powder particles are periodically removed from the outside of the filters by reverse air jet blowing. The high speed, high-pressure reversing jets operate for less than 0.2 seconds at 30 second intervals and, because they are applied to only part of the filter for a brief dwell time, they have no practical effect on the main air flow, thus giving a continuous filtration characteristic. The powder particles released from the cartridge filter then drop into a hopper to be sieved and returned to the system. Cartridge filters are extremely effective being up to 99% efficient. The degree of efficiency depends on the type of filter employed and the regularity of its cleaning. Attached to the material discharge of either cyclone or cartridge filter recovery system must be a dust tight seal, i.e. a rotary valve, with which the reclaimed powder can be metered after passing through an inline sieve into the virgin material.

### **Curing**

To polymerize the powder applied to the substrate we must heat both to a high temperature for a few minutes. This is the curing process. As powder coatings do not contain solvents (unlike liquid coatings) a flash zone is not required in the curing oven. The volume of exhaust gases is also substantially lower which can also substantially lower operational costs. The formulation of the powder coating material determines to a large extent the curing time and temperature of the coated object. It will also result in the specified film properties. Several curing oven types exist.

#### *Oven types:*

**Convection oven:** The most frequently used curing oven type and can be divided into directly fired and in-directly fired ovens. Fuel options are natural gas, propane, oil or electricity. In the case of a directly fired oven combustion gases can interfere seriously with the powder during curing and with film properties thereafter. In any oven care should be taken that no high air velocities exist or are created that could damage the virgin, or not yet solidified, powder coating layer. Acceptable air velocities are in the 1 to 2m/sec range.

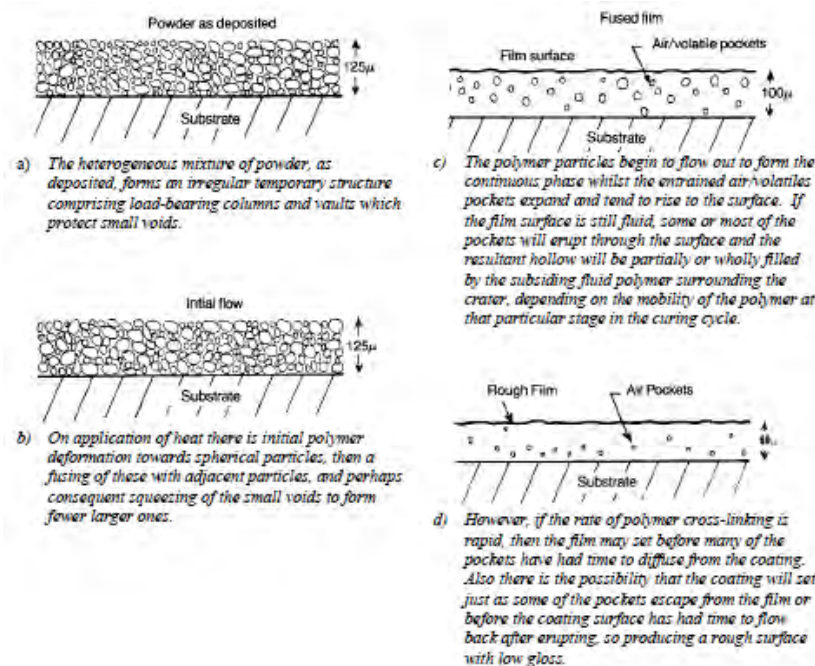
**Infrared oven:** Uses radiant energy to heat a product through electromagnetic waves. Infrared heating works very quickly. There are three types of emitters -

short, medium and long wave length. Their main performance differences are operating temperature (some 2000, 1050 and 600°C respectively) and radiation efficiency (80, 60 and 50% respectively). Higher temperatures result in faster heating rates and a lower efficiency which results in a higher loss through convection heat. Dual or combination oven: Both infra-red and convection are applied. In the infra-red section the powder film is melted to avoid powder being blown off in the convection section where additional time is available to complete the entire cross-linking process.

**Induction oven:** Heat is generated in the metal object through induction of eddy currents. The advantage being, as with infra-red, the powder coating can start reacting before contact with gas combustion components can take place.

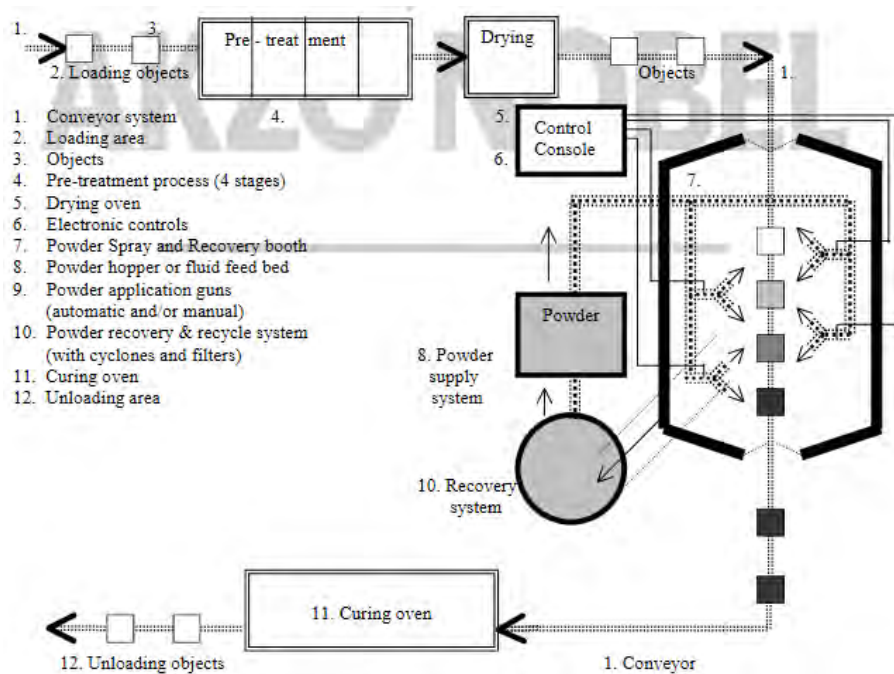
Medium temperature radiation offers the most effective source of heat for curing thermosetting powders. Gas fired emitter panels present a panel surface temperature of 900°C. Electric panels give a surface temperature of approximately 800°C. The work-pieces should be maintained at a distance of approximately 300mm from the emitter panels. Substrates coated with darker color powder absorb more infra-red radiation, while objects with light colored powder do not heat up as quickly. It is therefore recommended that each individual powder is tested in combination with the curing oven to evaluate the curing performance.

**Figure A- 3: The coating process stages in powder coating**



Many manufacturers, both European and worldwide offer a range of equipment as described above. This includes complete conveyor lines, pre-treatment systems, drying/curing ovens or individual items such as powder pumps, spray guns or even their adaptor parts. Each part of the coating system may be purchased from a specialist in that field (e.g. ovens, conveyors, booths) or the whole plant can be purchased from one ‘turn-key supplier’ who takes overall responsibility for the complete installation. One example of an automated powder coating line is provided below.

**Figure A- 4: The Automated Powder Coating line**



**PCI  
Powder vs. Liquid  
Operational Cost Analysis, rev. 0**

<b>Applied Material Cost</b>			
Variable	Notes	Liquid	Powder
Paint Cost	Liquid = \$ per Gal. (reduced), Powder = \$ per Lb.	\$18.00	\$3.00
% Solids by Volume	Reduced	35.0%	98.0%
Specific Gravity	Powder Only	N/A	1.4
Theoretical Coverage at 100% Utilization	Liquid = Sq. Ft./Gal., Powder = Sq. Ft./Lb.	561.4	134.6
% Material Utilization	see Table below	33.0%	89.0%
Average Film Thickness	Mils	1.20	2.00
Actual Coverage	Liquid = Sq. Ft./Gal., Powder = Sq. Ft./Lb.	154.4	59.9
Applied Cost	\$ per Sq. Ft.	\$0.1166	\$0.0501

<b>Material Utilization Percentages</b>	<b>Conventional Liquid</b>	<b>Electrostatic Liquid</b>	<b>Disc or Bell Liquid</b>	<b>Electrostatic Powder</b>
Utilization Efficiency	33%	50%	65%	89%

<b>Fuel Data</b>		<b>Oil</b>	<b>Electricity- Convection Cure</b>	<b>Electricity- IR Cure</b>	<b>Gas- Indirect Fire</b>	<b>Gas- Direct Fire</b>
Efficiency Percentage		75%	75%	90%	80%	90%
Cost	Costs: Oil = \$ per Ton, Gas = \$ per Therm, Electricity = \$ per KWH			Same as Convection Cure	\$0.38	Same as Indirect Fire

<b>Energy Costs- Spray Booth Exhaust</b>			
Variable	Notes	Liquid	Powder
Square Footage of All Booth Openings	Sq. Ft.	140.0	N/A
Face Velocity	FPM	100.0	N/A
CFM Exhausted	Cubic Ft. per Min.	14,000.0	Returned to Plant
Yearly Average Air Temperature	Degrees F.	49.0	N/A
Yearly Average Plant Air Temperature	Degrees F.	68.0	N/A
Make Up Air Temperature Difference	Degrees F.	19.0	N/A
Spray Booth Exhaust Required BTU's	BTU's per Hr.	292,600	N/A

<b>Energy Costs- Cure Oven Exhaust</b>			
Variable	Notes	Liquid	Powder
Part Surface Area Coated	Sq. Ft. per Hr.	2500.0	2500.0
Applied Coating	Liquid = Gal. per Hr., Powder = Lbs. per Hr.	16.2	41.7
Solvent Load	Gal. per Hr. or Lbs. per Hr.	10.5	0.8
Required Exhaust	330 CFM oven minimum	1,798	330
Oven Set Point Temperature	Degrees F.	300	375
Is the cure oven located inside the plant?	Yes or No	y	y
Is the cure oven direct fired?	Yes or No	y	y
Temperature Difference	Degrees F.	232	307
Cure Oven Exhaust Required BTU's	BTU's per Hr.	448,586	111,441

<b>Energy Costs- Conveyor, Part, and Cure Oven Heat Loss</b>			
Variable	Notes	Liquid	Powder
Conveyor Weight	Lbs. per Ft.	15.0	15.0
Hanger Weight	Lbs. per Ft.	10.0	10.0
Line Speed	FPM	15.0	15.0
Does the cure oven use electric IR energy?	Yes or No	n	n
Conveyor and Tooling Load	Lbs. per Hr.	22,500.0	22,500.0
Ware Load	Lbs. per Hr.	6,000.0	6,000.0
Total Load	Lbs. per Hr.	28,500.0	28,500.0
Total Oven Surface Area	Sq. Ft.	7,500.0	7,500.0
Specific Heat Load	see Table below	0.125	0.125
Total Load Loss	BTU's per Hr.	826,500	1,093,888
Oven Radiation Loss	BTU's per Hr. (assuming 4" thick insulation)	522,000	690,750
Load Loss Grand Total	BTU's per Hr.	1,348,500	1,784,438

<b>Specific Heat Load</b>	<b>Steel</b>	<b>Iron</b>	<b>Aluminum</b>
Heat Loads	0.125	0.13	0.248

<b>Energy Costs- Solvent Incineration</b>			
Variable	Notes	Liquid	Powder
Incineration Temperature	Degrees F.	750	N/A
Incineration Temperature Difference	Degrees F.	450	N/A
Oven Exhaust Incineration Energy	BTU's per Hr. CFM at 70 Degrees F.	870,102	N/A
Spray Booth Exhaust Incineration Energy	BTU's per Hr.	10,502,800	N/A
Total Required Incineration Energy	BTU's per Hr.	11,372,902	N/A
Incinerator Thermal Efficiency Percentage	see Table below	90.0%	N/A
Percent Net Required Input Energy	Percentage	10.0%	N/A
Total Energy "Recovered"	BTU's per Hr.	10,235,611	N/A
Net Incineration Input Energy	BTU's per Hr.	1,137,290	N/A

<b>Typical Thermal Efficiencies for Various Incinerator Designs</b>	
Thermal Incinerator with Heat Recovery	Regenerative Incinerator
50-60%	85-95%

<b>Total Energy Costs</b>			
Variable	Notes	Liquid	Powder
Spray Booth Exhaust Make-Up Air, Energy Source: Gas or Oil	Enter G or O for Gas or Oil	g	N/A
Spray Booth Exhaust Make-Up Air Costs	\$ per Hr.	\$1,389.9	N/A
Cure Oven Exhaust, Energy Source: Gas, Electricity, or Oil	Enter G, E, or O for Gas, Electricity, or Oil	g	g
Cure Oven Exhaust Costs	\$ per Hr.	\$1,894.0	\$0.4705
Conveyor, Part, and Oven Radiation Loss	Enter G, E, IR, or O for Gas, Electricity, Infrared, or Oil	g	g
Conveyor, Part, and Oven Radiation Loss Costs	\$ per Hr.	\$5,693.7	\$7,634.3
Oven Make-Up Air, Energy Source: Gas or Oil	Enter G or O for Gas or Oil	g	g
Oven Make-Up Air Costs	\$ per Hr.	\$0.1745	\$0.0328
Solvent Incineration, Energy Source: Gas or Oil	Enter G or O for Gas or Oil	g	N/A
Solvent Incineration Costs	\$ per Hr.	\$4,801.9	N/A
Required Flash Tunnel Exhaust	CFM	10,000	N/A
Flash Tunnel, Energy Source: Gas or Oil	Enter G or O for Gas or Oil	g	N/A
Flash Tunnel Costs	\$ per Hr.	\$0.9928	N/A
Total Energy Costs	\$ per Hr.	\$14,946.7	\$8,037.6

<b>Labor and Maintenance Costs</b>			
Variable	Notes	Liquid	Powder
Line Supervisors	Number of each.	1	1
Supervisor Compensation	\$ per Hr.	\$20.50	\$20.50
Total Supervisors' Compensation	\$ per Hr.	\$20.50	\$20.50
Line Operators	Number of each.	2	2
Operator Compensation	\$ per Hr.	\$10.25	\$10.25
Total Operators' Compensation	\$ per Hr.	\$20.50	\$20.50
Clean Up Man-hours per Shift	Hrs.	1.5	1
Clean Up Labor Compensation	\$ per Hr.	\$10.25	\$10.25
Number of Operating Hours per Shift	Operating Hrs. per Shift	8.0	8.0
Number of Operating Hours per Year	Operating Hrs. per Year	2000	2000
Clean Up Cost	\$ per Hr.	\$1.92	\$1.28
Available Sludge	Liquid = Gal. per Hr., Powder = Lbs. per Hr.	3.8	4.5
Sludge Disposal Cost	Liquid = \$ per Gal., Powder = \$ per Lb.	\$45.00	
Sludge Cost	\$ per Hr.	\$170.88	\$0.00
Maintenance Hours per Year	Hrs. per Year	125.0	75.0
Maintenance Costs per Hour	\$ per Hr.	\$10.2500	\$10.2500
Yearly Replacement Parts Cost	\$ per Year	\$5,000.00	\$2,500.00
Total Maintenance Costs per Hour	\$ per Hr.	\$3.1406	\$1.6344
Cost per Filter	\$ per Filter	\$1.00	\$50.00
Number of Filters per Year	Filters per Year	120	6
Filter Costs per Hour	\$ per Hr.	\$0.0800	\$0.1500
Total Labor and Maintenance Costs per Hour	\$ per Hr.	\$217.0021	\$44.0656

<b>Miscellaneous Costs</b>			
Variable	Notes	Liquid	Powder
Equipment Depreciation	\$ per Year		
Reject/Rework Cost Factor, expressed as a percentage of the sum of the energy, material, and labor costs	This factor is typically 4-8% for liquid and 2-4% for powder	8.0%	2.0%
Reject/Rework Costs	\$ per Year	\$83,748	\$7,092
Total Miscellaneous Costs	\$ per Year	\$83,748	\$7,092

<b>Operating Cost Summary</b>			
Variable	Notes	Liquid	Powder
Total Material Costs per Year	\$ per Year	\$ 582,958	\$ 250,411
Total Energy Costs per Year	\$ per Year	\$ 29,893	\$ 16,075
Total Labor and Maintenance Costs per Year	\$ per Year	\$ 434,004	\$ 88,131
Total Miscellaneous Costs	\$ per Year	\$ 83,748	\$ 7,092
Total Operating Costs per Year	\$ per Year	\$ 1,130,604	\$ 361,710
Annualized Cost per Square Foot	\$ per Sq. Ft. for the given year	\$ 0.2261	\$ 0.0723