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Generic Scenario: Electrostatic Application of Powder Coatings

Introduction

Electrostatic application is one of two methods for applying powder coatings to substrates. More than 90% of all powder coatings sold in the United States are applied by electrostatics. More than 3,000 facilities in the USA use this application method. Fluidized-bed application is the least used method for applying powder coatings, especially those with complex geometry.

Market Share

Electrostatic spray application of powder coatings is the most widely used method of applying powder coatings [5], accounting for the application of approximately 90 to 95% of all of the powder coatings sold in the United States [9]. Fluidized-ed application accounts for the remaining portion. Powders applied by electrostatic spray are manufactured predominantly by melt-blending techniques. During this process, the raw materials usually are bound into the resin matrix, thus removing any threat of chemical reactivity of the raw constituents. Currently, it is estimated that there are more than 3,000 facilities in the USA with powder coating capabilities [3]. Facilities range in size from one gun and no booth for applications in small job shops, to applications in large-scale assembly line coating processes using multiple booths with multiple guns.

Powder coating manufacture in the USA has grown at a rate exceeding 10% for the past 10 years, and growth is expected to continue at this rate at least through 1995 [1,2]. The total powder coating market in the USA in 1991 was estimated to be 133.5 million pounds, at a market value of $13.5 million [2,3,4]. Powder coatings are divided into two classes according to the type of resin material used in the manufacture of the powder coat. Thermoset powder coats account for more than 90% of the powder coating market, having a total market volume of 122 million pounds in 1991 [3]. Thermoplastic powder coatings account for the remaining 11.5 million pounds [4]. Based on these figures, 91% of the powder coating market is assumed to be based on thermoset resin systems, and the remaining 9% of the market is thermoplastic powder coatings.

Process Description

Electrostatic application of powder coating encompasses two methods of application that differ primarily in the manner in which the charge is imparted to the powder particles. 'Corona' charge spray guns are the most common [10]. These guns use a high-voltage source (30 to 100 kV) to create an electrostatic field between the gun and a grounded part. The field is strong enough to break down the air at the tip of the gun, creating free ions that charge the powder particles as they pass through the tip of the gun [10]. The diffuse, charged particles then are directed to the workpiece by the air currents forcing the powder through the gun tip. Electrostatic forces attract the charged particles to the grounded part, coating the workpiece with the powder product [5,10]. Triboelectric guns are the other method used to apply powder coatings electrostatically. In triboelectric guns, no electric fields are used. Instead, high-velocity powder particles are passed through the triboelectric gun barrel, which is lined with a charging surface. Friction generated between the particles and the charging surface in the gun imparts a charge to the particles. As the particles are expelled from the gun they are directed toward the grounded workpiece [11]. Each of these application methods offers its advantages and disadvantages.

A flow diagram for a typical electrostatic powder coating line is shown in Figure 1. The powder coating is poured into a feed hopper that serves to supply powder to the gun. Powder coatings typically are supplied in 50-lb boxes; however, a number of applicators using large quantities of powder currently are being supplied powder products in 55-gal drums that require the use of a special pump to deliver powder directly from the drum.

The application of powder typically is performed in a powder spray booth, as shown in Figure 2. The booth serves two purposes:

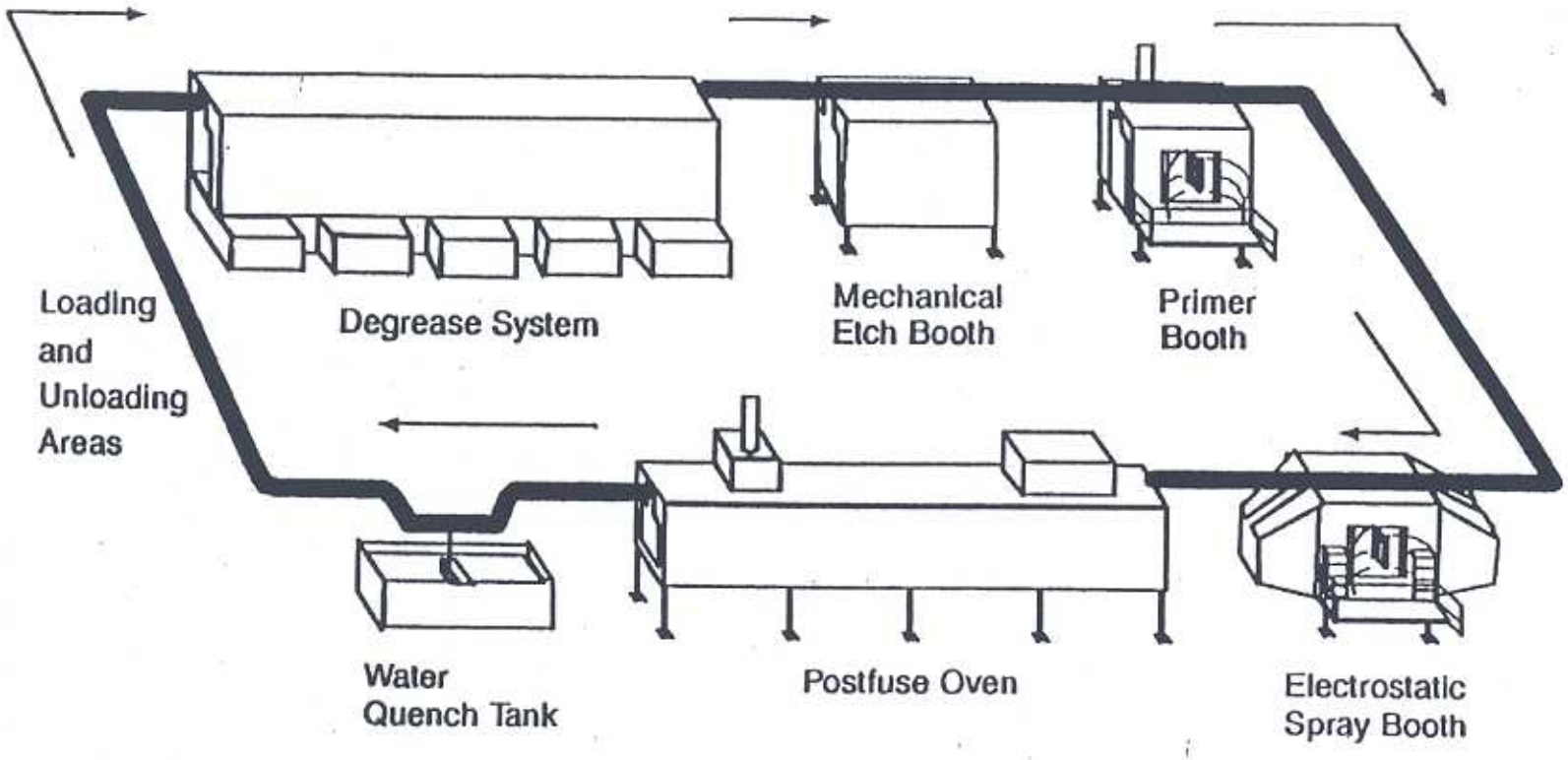

Figure 1. Electrostatic spray process coating line [16].

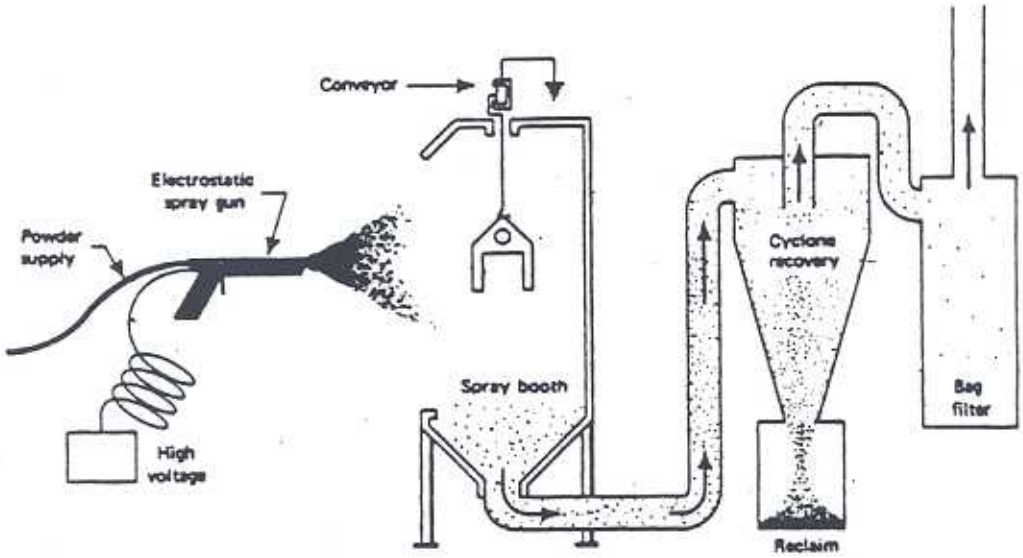

Figure 2. Electrostatic powder coating application showing gun, spray booth, and cyclone recovery system [17].

1. To supply enough air to the powder spray area to maintain the powder-air mixture at 50% of its minimum explosion concentration (MEC) of powder (MECs for most powder coatings are in the range of 45 to 91 g/m^3)
2. To provide a mechanism for containment and removal of the powder overspray for reuse or disposal [10,13].

Several methods are available to reclaim the powder overspray from the spray booth. Conventional cyclone systems collect 80 to 90% of the powder for reclaim. Systems utilizing a filter belt or mini-cyclones are approximately 90 to 95% efficient, and newer cartridge filter systems can achieve collection efficiencies up to 98% [10,12]. Absolute filters are used to remove the powder fines from the airstream before the air is exhausted back into the working environment [10,12]. Reclaimed powder can be reused, and typically is blended with the virgin powder material at a ratio of 1:1. The use of reclaimed powder makes it possible to achieve the 95 to 99% use efficiency typically reported for powder spray systems. An industry average of 95% powder use rate for powder reclaim systems can be assumed [3,15]. The 5% powder loss is due primarily to powder coating of the hangers used to support and ground the workpieces. Other powder losses occur during hopper loading, during cleanup, and from filter retention. It currently is estimated that 60% of all powder sprayed is collected and reused [15]. Overspray from the remaining 40% is disposed of as waste.

High use rates typically are for one-color applications and long runs. Use efficiency typically decreases during shorter runs and color changes, as all equipment has to be cleaned between color changes to prevent contamination. Spray equipment and cyclone systems can be cleaned with purge air. Hoppers and cartridge

filters typically are switched out. Spray booths are manually wiped down using damp cloths or rubber squeegees. Cleaning for color changes typically results in a 45-minute to 1-hour downtime.

After the application of the powder coatings, coated products are heated in ovens to allow for continuous film formation. Residence time in the oven and oven temperatures are determined by the type of resin system used in the powder coating. Cure of thermoset powder coatings may require anywhere from 5 to 30 minutes at temperatures from 250 to 450°F.

Composition

The five major types of thermoset powder coatings have the following market shares [1]: epoxy (29%), epoxy/polyester hybrids (17%), TGIC polyesters (21%), polyurethanes-polyester and acrylic (32%), and acrylic (1%). During cure, thermoset resins melt, flow, and chemically react with themselves or with other curing agents to form a continuous, crosslinked, high-molecular-weight film that is chemically different from the base resin [5]. Once cured, the coating will not flow upon reheating. A typical thermoset powder formulation consists of:

- 60 to 70% resin and hardener (of which 80% is resin and 20% is hardener or curing agent)
- 26 to 38% fillers and pigments
- 2 to 4% levelers and processing aids
- 1% plasticizers and stabilizers [6].

Formulations for thermoplastic powder systems contain no curing agents, require less pigmentation as they are applied in thicker films (more resin), and may be highly plasticized at the expense of resin (15% in some PVC powder coats). These powders typically are high-molecular-weight resins that flow to form a continuous film upon heating. No crosslinking occurs during heating, so the resin chemistry remains the same and the coating is capable of flow upon any further application of heat. The thermoplastic powder market is dominated by PVC resin-based systems (73%), followed by nylons (23%). The remaining thermoplastic market is divided among polyethylenes, polypropylenes, thermoplastic polyesters, fluoropolymers, and polyphenylene sulfide [4,7].

Waste Generation, Environmental Releases, and Exposure-Level Calculations

Waste Generation

The specific gravity of the powder product may range between 1.2 and 1.8, with 1.6 being a typical value for thermoset powders. Powders manufactured for electrostatic application typically are ground to 25 to 40 microns in size. A small percentage of fines (less than 10%), particulates less than 10 microns in size, remain in the powder product. Because of the size of the powder particles, powder coatings are classified as nuisance dusts. The threshold limit value (TLV) of the respirable portion of these dusts (particles 5 microns in diameter or less) is 5 mg/m^3, with an overall TLV of 15 mg/m^3 [8]. An average-size feed hopper used for powder coating application holds about 200 lb of powder. Powder from the feed hopper is fed to the gun by siphoning or pumping the fluidized powder through the powder feed hose going to the gun. The spray gun charges the powder, and the feed air directs it towards the workpiece in the form of a diffuse cloud of charged powder. The deposition rate of the powder on the workpiece is determined primarily by the flow rate of the air used to feed the powder to the gun, and by the strength of the electrostatic forces depositing the powder coating on the grounded part. Typically, powder is expelled from a gun at a rate of about 25 lb/hr [15]. Deposition rates for both manual and automatic powder application typically are of the order of 50% to 65% of the powder leaving the gun, primarily depending on the geometry of the part being coated [5,12]. A typical automatic spray system for industrial applications will use between 8 and 12 automatic guns, and 1 or 2 guns for manual touchup.

The emission of gaseous products during cure may range from 0.5 to 2% by weight of the powder product, depending on the resin system and the curing mechanism [14]. Air exchanges in the oven are performed at a rate of 4 to 8 per minute, depending on the size of the parts being coated and the oven size. Typically, 90% of the exhausted air is recirculated through the oven heaters to burn off the by-products in the airstream; the remaining 10% is exhausted to the atmosphere [9]. Similar exhaust emissions, as well as thermal by-products and ash, may come from pyrolysis cleaning of the hangers that hold and ground the part being coated. Powder deposited on hangers may account for most of the waste generated during a reclaim application [9].

Environmental Releases

Variables/Assumptions:

- AC: annual consumption; 1991 consumption of powder was 133.5 x 10^6 lb
- ES: % electrostatically sprayed; 92% of powder consumed in 1991 was electrostatically sprayed
- RC: % reclaimed; 60% of all powder sprayed is reclaimed
- UF: (use efficiency) powder use efficiency of 95% when using reclaim (5% waste)
- NR: % powder not reclaimed; 40% of all powder sprayed is not reclaimed
- TE: transfer efficiency of guns; 60% assumed (40% waste)
- VC: volatile compounds; 1.5% assumed
- FE: filter efficiency; 99% assumed; 1% loss of particulates (less than 1 micron) to air
- FP: filtered powder; assumed 1% of powder sprayed makes it to final filter
- H: 8-hour shift, SH: 1 shift per day, DOP: 250 days of production per year
- B: booths; assume 1 booth
- G: guns, assume 1 manual and 8 automatic; 9 guns/booth
- OR: output rate of guns; 25 lb/hr/gun assumed
- PE: production efficiency; booth operating 70% of time
- PMN: weight fraction of PMN material; given by manufacturer
- CR: concentration of respirable dust (5 mg/m^3)
- IR: inhalation rate (1.25 mg/hr)[18]
- TR: number of times/day powder materials handled
- T: time of exposure per transfer/handling operation
- N: number of U.S. sites is 3,000

Gross Calculations

Due to the large number of powder coating facilities in the USA, and the diversity among these facilities, it is not reasonable to devise a 'typical' powder coating facility from which per annum calculations can be extrapolated effectively. As such, gross calculations for environmental releases will be provided based on the annual consumption of powder. Generic calculations will assume a typical automated operation. No distinction is made for corona vs. tribo spray, as both methods may be equally efficient.

Gross calculations provide a reasonable estimate of the annual waste generated by electrostatic spray application of powder coatings based on current market information.

Solid Waste: Assume all powder not remaining on workpiece is solid waste; no compensation is made for ash generated during pyrolysis cleaning of hooks/hangers, which accounts for approximately 2% of the waste.

Reclaim Facilities: General: PMN × AC × ES × RC × (1-UF) × 0.454 kg/lb = ??? kg/year

1991: $133.5 \times 10^6 \times 0.92 \times 0.60 \times (1-0.95) \times 0.454 = 11.7 \times 10^6$ kg/year total powder

Non-Reclaim Facilities: General: PMN × AC × ES × NR × (1−TE) × 0.454 kg/lb = ??? kg/year

1991: $133.5 \times 10^6 \times 0.92 \times 0.40 \times (1-0.60) \times 0.454 = 8.9 \times 10^5$ kg/year total powder

Air Emissions: Two types of air emissions are possible, gaseous products and particulate matter. For gaseous, assume all weight loss during the cure of the coating is due to emission of gaseous volatiles. For particulate matter, all booth air is filtered and then released back into the workplace, or through a baghouse and then to the outside. Divide by number of sites for kg/site/year.

$F_{PMN} \times RATE_{consumption} \times F_{powder_spray} \times [(F_{powder_reclaim} \times EFF_{use}) + (F_{powder_nonreclaim} \times EFF_{gun})] \times F_{volatile} \times 0.454 \frac{kg}{lb}$

Gaseous: General: PMN × AC × ES × [(RC × UE) + (NR × TE)] × VC × 0.454 kg/lb = ??? kg/year

1991: $133.5 \times 10^6 \times 0.92 \times [(0.60 \times 0.95) + (0.40 \times 0.60)] \times 0.015 \times 0.454 = 6.76 \times 10^5$ kg/year $\times F_{PMN}$

$F_{PMN} \times RATE_{consumption} \times F_{powder_spray} \times F_{powder_filter} \times (1 - EFF_{filter}) \times 0.454$

Particulates: General: PMN × AC × ES × FP × (1−FE) × 0.454 kg/lb = ??? kg/year

1991: $133.5 \times 10^6 \times 0.92 \times 0.01 \times (1-0.99) \times 0.454 = 5{,}576$ kg/year

Water: None assumed.

Generic Calculations

Generic calculations assume automated electrostatic spray application in one booth using a 200-lb feed hopper, 9 guns (8 automatic and 1 manual), and a powder use rate of lb/h/gun. One booth typically is run by 2 to 3 workers, working 8-hour shifts 250 days a year. All calculations are presented on a per site basis.

Powder Consumption per Shift (PC/Sh): PC does AC = PC ? I am assuming yes.

B × G × OR × H × PE × 0.454 kg/lb = ??? kg/site/shift

$N_{booth} \times N_{gun} \times RATE_{gun} \times T_{shift} \times EFF_{operating} \times 0.454$

1 × 9 × 25 × 8 × 0.70 × 0.454 kg/lb = 572 kg/site/shift

$\left(\frac{booth}{site}\right)\left(\frac{guns}{booth}\right)\left(\frac{lb}{hr\text{-}gun}\right)\left(\frac{hours}{shift}\right)\left(-\right)\left(\frac{kg}{lb}\right) = \frac{kg}{site\text{-}shift}$

Annual Powder Consumption (PC/y):

B × G × OR × H × PE × Sh × DOP × 0.454 kg/lb = ??? kg/site/year

$N_{booth} \times N_{gun} \times RATE_{gun} \times T_{shift} \times EFF_{operating} \times N_{shift} \times T_{production}$

1 × 9 × 25 × 8 × 0.70 × 1 × 250 × 0.454 kg/lb = 143,010 kg/site/year

$\left(\frac{booth}{site}\right)\left(\frac{guns}{booth}\right)\left(\frac{lb}{hr\text{-}gun}\right)\left(\frac{hr}{shift}\right)\left(-\right)\left(\frac{shift}{day}\right)\left(\frac{day}{yr}\right)\left(\frac{kg}{lb}\right) = \frac{kg}{site\text{-}yr}$

Solid Waste:

Reclaim Facilities:

PMN × B × G × OR × H × PE × Sh × DOP × (1−UE) × 0.454 kg/lb = ??? kg/site year

$F_{PMN} \times N_{booth} \times N_{gun} \times RATE_{gun} \times T_{shift} \times EFF_{operating} \times N_{shift} \times T_{production} \times (1 - EFF_{use}) \times 0.454$

1 × 9 × 25 × 8 × 0.70 × 1 × 250 × (1−0.95) × 0.454 kg/lb = 7,150 kg/site/year

$F_{PMN} \times \left(\frac{none}{}\right)\left(\frac{booth}{site}\right)\left(\frac{guns}{booth}\right)\left(\frac{lb}{hr\text{-}gun}\right)\left(\frac{hrs}{shift}\right)\left(\frac{none}{}\right)\left(\frac{shift}{day}\right)\left(\frac{day}{yr}\right)\left(1 - \frac{none}{}\right)\left(\frac{kg}{lb}\right) \quad \frac{kg}{site\text{-}yr}$

Non-Reclaim Facilities:

PMN × B × G × OR × H × PE × Sh × DOP × (1−TE) × 0.454 kg/lb = ??? kg/site/year

$(1 - EFF_{gun})$

$1 \times 9 \times 25 \times 8 \times 0.70 \times 1 \times 250 \times (1-0.60) \times 0.454$ kg/lb =
57,204 kg/site/year

Air Emissions:

Gaseous: $N_{booth} \times N_{gun} \times RATE_{gun} \times T_{shift} \times EFF_{operator} \times N_{shift} \times T_{production} \times [(F_{powder_reclaim} \times EFF_{use}) + (F_{powder_non\text{-}reclaim} \times EFF_{gun})] \times F_{volatile} \times 0.454$

Elect air gas

$B \times G \times OR \times H \times PE \times Sh \times DOP \times [(RC \times UE) + (NR \times TE)] \times VC \times 0.454$ kg/lb =
??? kg/site/year

$\left(\frac{booths}{site}\right)\left(\frac{guns}{booth}\right)\left(\frac{lb\text{-}gun}{hr}\right)\left(\frac{hrs}{shift}\right)(\text{none})\left(\frac{shifts}{day}\right)\left(\frac{days}{yr}\right)\left[(\text{none} \times \text{none}) + (\text{none} \times \text{none})\right] \times \text{none} \times ($

$1 \times 9 \times 25 \times 8 \times 0.70 \times 1 \times 250 \times [(0.60 \times 0.95) + (0.40 \times 0.60)] \times 0.015 \times 0.454$ kg/lb
= 1737 kg/site/year

Particulates:

$PMN \times B \times G \times OR \times H \times PE \times Sh \times DOP \times FP \times (1-FE) \times 0.454$ kg/lb =
??? kg/site/year

Elect air particulates

$1 \times 9 \times 25 \times 8 \times 0.70 \times 1 \times 250 \times 0.01 \times (1-0.99) \times 0.454$ kg/lb = 14.3 kg/site/year

Water: None assumed.

Worker Exposure (1 worker; 8-hour shift; 1 day)

Powders are classified as nuisance dusts, with an overall permissible exposure limit (PEL) of 15 mg/m^3. The PEL for the respirable portion of powder coatings is assumed to be 5 mg/m^3. It is assumed that all facilities manufacturing powder coatings are in compliance with these Occupational Safety and Health Act (OSHA) standards, so worst-case exposure will be to a concentration equal to the PEL [18]. Exposure levels are determined for 1 worker, working one 8-hour shift at one booth. Two to three workers may perform operations at a given spray booth. Worker exposure is limited to tasks involving handling of the powder materials or coated products during the application process. Exposure levels vary according to specific tasks and the frequency at which these tasks are performed.

Inhalation Exposure: An inhalation rate of 1.25 m^3/hr or 10 m^3/day is assumed [18]. Powders are classified as nuisance dusts, with an overall PEL of 15 mg/m^3. The OSHA PEL for the respirable portion of the dust can be assumed to be 5 mg/m^3.

$$CR\ (5\ mg/m^3) \times PMN \times 10\ m^3/day = ?(mg/day)$$

Dermal Exposure: Dermal exposure is limited to incidental exposure during powder handling or handling of the coated pieces prior to oven exposure. Equations approximating exposure levels are based on data compiled on contact operations as given in CEB (1991, Table 4-13)[18].

$$(6{,}500 - 18{,}200\ mg/m^3 \times PMN \times TR \times T_t = ?(mg/day)$$

Disposal Concerns

All powdered waste generated is placed in secondary containers and covered in a landfill. Some powder waste is solidified in ovens to facilitate nonhazardous disposal. As 100% containment of materials cannot be assumed. behavior of the waste in landfill may be of concern. Solubility and leach test data on the PMN material must be provided by the manufacturer submitting the PMN.

Pyrolysis typically is used to clean powder coatings from the hooks and hangers supporting and grounding the coated parts. The amount of powder remaining on these parts may constitute 2% of the 5% total waste, i.e., 2% of the powder coating used daily. Products from pyrolysis are expected to be b product gases and ash.

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