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Generic Scenario: Fluidized-Bed Application of Powder Coatings

Introduction

Fluidized-bed application is one of two methods for applying powder coatings to substrates. Most thermoplastic powder coatings, especially those on parts with complex geometry, are applied by this method. However, the most widely used powder coating application method in the United States is now electrostatic spray.

Market Share

Fluidized-bed application of powder coatings dates back to the mid-1950s, making it one of the first methods of application of powder coatings [5]. Recent advances in electrostatic spray application of powder coatings and improvements in powder coating formulations have reduced the use of fluidized-bed application methods. Today, approximately 90 to 95% of all of the powder coatings sold in the United States are applied by electrostatic spray [7]. Of the 3,000 plus facilities in the USA with powder coating capabilities, only a small percentage utilize fluidized-bed application methods [8]. The market share of powders applied by the fluidized-bed method is fairly stable, at 5 to 10% of the powders sold in the USA.

Fluidized-bed application of powder coatings offers some significant advantages over electrostatic spray application for powder coatings applied for functional purposes, and for the application of powder coatings to complex geometries and wire goods. More than 95% of fluidized-bed applications use thermoplastic powder coatings [8]; thus, this method of application accounts for the use of a major portion of the thermoplastic powder market, but only a small percentage of the thermoset market [9].

Powder coating manufacture in the United States 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 coatings account for over 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 [4,5]. 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

In the typical fluidized-bed powder coating application as shown in Figure 1, parts to be coated are:

- degreased and mechanically cleaned
- sprayed with primer
- preheated in a convection oven
- dipped in a tank of fluidized powder
- air-cooled or water quenched

The coating thickness is determined by the properties of the powder, the temperature of the metal part being coated, and the time of immersion in the fluid bed. Part temperature is controlled by the physical properties of the part and the part geometry. Heavier, thicker parts have more thermal mass and must be preheated for longer periods of time to achieve a satisfactory immersion temperature for proper coating, but do not need to be heated to such high temperatures, as the extra thermal mass also will drive the powder fusion process during immersion. Typically, parts are heated between 500 to 700°F, or about 100°F above the fusion point or glass transition of the powder coating [11,12,13]. Once the part is removed from the oven, it is immediately (on order of 5 seconds) dipped in the fluidized bed of powder and agitated to enhance even coatings [12]. With a given preheated part, the time of immersion determines the coating film thickness. As the powder particles fuse to the part and flow to form a continuous film, the coating becomes a thermal insulating layer and eventually

lowers the contact temperature below the critical temperature for powder fusion, thus providing a limit to the coating thickness [11]. After the fluidized-bed dipping, the parts typically are passed through a post-heat oven to ensure that the final powder particles attached to the coating are completely fused [11]. Film thicknesses of 5 to 50 mils can be obtained using fluidized-bed application [12]. A typical film thickness of 10 to 15 mils can be obtained in as little as 5 seconds using nylon powders and a properly heated part [10].

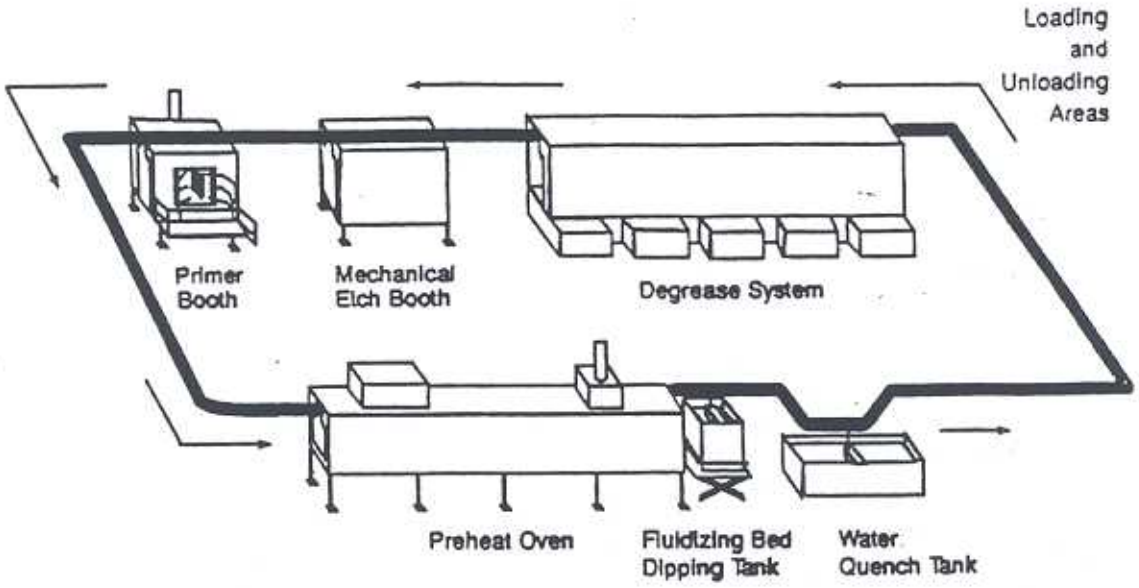

Figure 1. Powder application by fluidized bed process [20]

The fluid bed tank is a specially constructed tank with upper and lower compartments separated from each other by a porous divider [14] (Figure 2). The porous divider is a fine plate that will support the powder while still allowing air to flow through it in a uniform manner [15]. Powder coating is poured into the top compartment to a level about half full [12]. Air is then blown into the lower compartment at low pressure, where it passes uniformly through the porous divider and the powder [14]. The powder becomes supported by the air flow, expands, and forms a 'fluid-like' body of powder in the upper compartment [14]. The tank may be vibrated to aid proper fluidization. The powder level may be adjusted to the fill line either manually or automatically using reserve powder in feed hoppers. The walls of the bed extend sufficiently past the fill line to confine the powder to the fluidized-bed. In some cases a peripheral exhaust system may be added to collect stray powder and direct it for disposal or reclaim it for reuse [14,16].

The size of the fluidized-bed tank depends on the articles being coated. It may be small enough to coat belt buckles or large enough to coat light poles [12]. PVC thermoplastic powders, the most often used powders in fluidized-bed applications, have a density of 35 lb/ft^3 in the fluid state [17]. Thus, a bed measuring $4 \times 4 \times 4$ ft^3 holds approximately 2,240 lb of powder. The proper loading of powder in the fluidized bed must be maintained at all times to ensure the parts are properly coated. Powder consumption depends on the part being coated, the desired film thickness, and the production rate. The production rate typically is limited by the oven preheat step [16]. An automated process in which wire dishwasher racks are powder coated (a

major market for fluidized-bed powder coating) may coat 600 racks per hour, at a deposition rate of approximately ½ lb of powder per rack, consuming 300 lb of powder per hour [17]. Manual coating by fluidized bed is a slower process. Wire goods may be coated at a rate of 40 to 100 per hour by manual dipping, whereas larger parts using 2 to 2.5 lb of powder per part may be coated at a rate of 10 to 12 per hour [9].

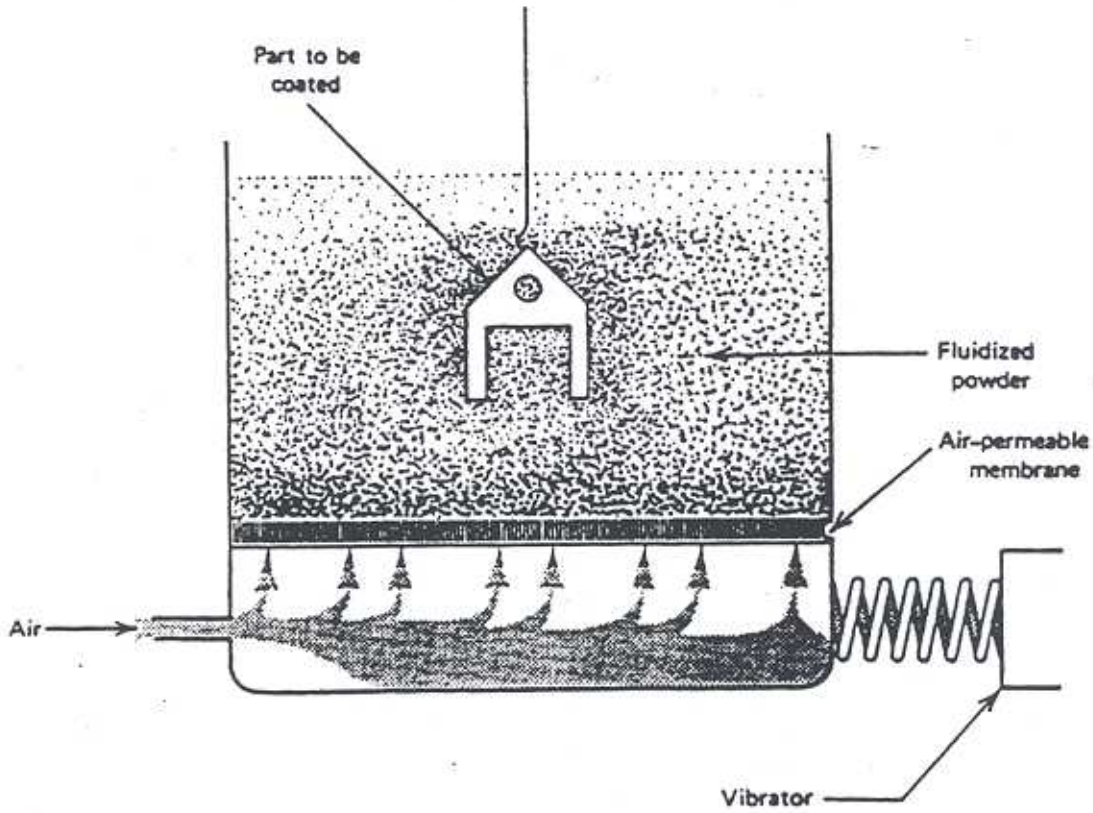

Figure 2. Typical fluidized bed for application of powder coatings [19]

Powder Coating Composition

There are five major types of thermoset powder coatings (thermoset powder market share also is given) [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 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, and 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

Due to the large number of powder coating facilities in the USA, the diversity among these facilities, and the small percentage of facilities that actually use fluidized-bed techniques, it is not reasonable to devise a 'typical' fluidized-bed powder coating facility from which per annum calculations can be effectively extrapolated. As such, gross calculations for environmental releases will be provided based on the annual consumption of powder. Generic calculations will assume automated processes for waste generation and worker exposure, as automated fluidized-bed lines account for the use of most of the powder applied by fluidized bed and pose the most significant worker threat.

Waste Generation

Fluidized-bed powder coating is considered to be extremely efficient in terms of powder usage. Most of the waste generated comes from the following procedures:

- pouring the powder into the fluid bed tank and feed hoppers
- dusting from the top of the fluid due to agitation or part dipping
- powder fines caught in safety exhaust ducts that are not reclaimed
- cleaning of the fluidized bed after a production run is complete [10].

Most powder coatings are shipped in 50-lb bags. It is estimated that ¼ to ½ lb of powder remains in the bag after the product is poured from the bag [18]. Thus, 1% of the powder used to keep the fluidized-bed tank to acceptable levels can be considered waste. After a run is completed, the powder is removed from the bed and placed in containers. The tank is then vacuumed clean of residual powder. Another 1% of waste will be assumed in this process. Powder loss of 1% will be assumed during the actual fluidized-bed coating operation. Conservatively, a 3% total powder waste generation will be assumed during the actual fluidized-bed coating operation. Conservatively, a 3% total powder waste generation will be assumed during the actual fluidized-bed coating operation. Conservatively, a 3% total powder waste generation will be assumed for fluidized-bed powder application. This loss will be based on the total amount of powder added to the tank during part coating.

Environmental Releases (kg/year)

Variables/Assumptions:

F_{PMN} - PMN: weight fraction of PMN material

RATE consumption - AC: annual consumption: 1991 consumption of powder was 133.5 x 10^6 lb

- FB: % of powder applied by fluid bed: 8% assumed
- SW: solid powder waste: 2%
- D: powder loss due to dusting: 1%

EFF_{filter} - FE: filter efficiency: 99%

- H: 8-hour shifts: Sh: 2 shifts per day, DOP: 250 days of production per year

RATE production - PR: production rate: 550 parts/hr

$H = T_{shift}$

$Sh = N_{shift}$

$DOP = T_{production}$

EFF production - PE: production efficiency; actually running 70% of shift time
- PC: powder coating applied per part; 0.5 lb/part
Crespirable. constituent - CR: concentration of respirable dust (5 mg/m^3)
RATE breathing - IR: inhalation rate (1.75 mg/hr) [21]
- TR: number of times/day powder materials handled
Texposure transfer - T_t: time of exposure per transfer/handling operation

1. Gross Calculations

Gross calculations will provide a reasonable estimate of the annual waste generated by fluidized-bed application of powder coatings based on current market information. Total product waste is assumed to be 3%. Assume 2% powder solids from loading and cleanup, and 1% waste from dusting. A filter efficiency of 99% is assumed; thus 99% of dust is disposed of as solids and 1% (particulates) is exhausted to air.

Solid Waste: General: PMN × AC × FB × [SW + (FE × D)] × 0.454 kg/lb = ???kg/year

1991: $133.5 \times 10^6 \times 0.08 \times [0.02 + (0.99 \times 0.01)] \times 0.454$ kg/lb
$= 1.45 \times 10^5$???kg/year

Air Emissions: General: PMN × AC × FB × [(1-FE) × D] × 0.454 kg/lb = ???kg/year

1991: $133.5 \times 10^6 \times 0.08 \times (1-0.99) \times 0.01] \times 0.454$ kg/lb = 485 ???kg/year

Water: None assumed.

2. Generic Calculations

Generic calculations assume automated fluidized-bed coating in a tank with a 1,000-lb powder capacity. It is assumed that the line is producing 70% of the time during an 8-hour shift, at a production rate of 500 parts per hour being coated with 0.5 lb of powder per part; 3 workers will be working 2 shifts a day, 250 days a year. All calculations are given on a per site basis.

Note: An additional 1,000 lb of powder is necessary to fill the fluidized-bed tank initially.

Powder Consumption per Shift (PC/Sh):

PR × PC × H × PE × 0.454 kg/lb = ???kg/site/shift

$500 \times 0.5 \times 8 \times 0.7 \times 0.454$ kg/lb = 636 kg/site/shift

Annual Powder Consumption (PC/y):

PR × PC × H × Sh × PE × DOP × 0.454 kg.lb = ???kg/site/year

$500 \times 0.5 \times 8 \times 2 \times 0.7 \times 250 \times 0.454$ kg/lb = 3.2×10^5 kg/site/year

Solid Waste: General: PMN × [(PR × PC × H × Sh × PE × DOP) + 1,000] × [SW + (FE × D)] × 0.454 kg/lb = ???kg/site/year

[(500 × 0.5 × 8 × 2 × 0.7 × 250) + 1,000] × [(0.02 = (0.99 × 0.01)] × 0.454 kg/lb = 9,534 kg/site/year

Air Emissions: General: $PMN \times [(PR \times PC \times H \times Sh \times PE \times DOP) + 1{,}000] \times [(1-FE) \times D] \times 0.454$ kg/lb = ???kg/site/year

$[(500 \times 0.5 \times 8 \times 2 \times 0.7 \times 250) + 1{,}000] \times [(1-0.99 \times 0.01)] \times 0.454$ kg/lb = 32 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 the Occupational Health and Safety Act (OSHA) standards, so worst-case exposure will be to a concentration equal to the PEL [21]. Exposure levels are determined for 1 worker, working one 8-hour shift. Up to three workers may man operations at a given fluidized bed. Worker exposure will be limited to tasks involving handling of the powder materials 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 1.75 m^3/hr or 10m^3/day is assumed [21]. 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 from contact operations as given in CEB (1991, Table 4-13) [21].

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

Disposal Concerns

All powdered waste generated should be 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 the landfill may be of concern. Solubility and leach test data on the PMN material must be provided by the manufacturer submitting the PMN.

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