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Generic Scenario: Melt-Blend Processing of Powder Coatings

Introduction

Melt-blend processing is the most common method for manufacturing powder coatings in the United States. Almost all thermoset powders and as much as 19% of the thermoplastic powders are produced by this process. About 81% of thermoplastic powders are produced by dry blending.

In the melt-blending process, dry, powdered raw materials are blended mechanically, followed by mixing in a melt mixing device. The melt product is cooled and reduced to the desired size.

Market Share

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, 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 are applied in relatively thin layers, mainly for decorative and protective applications. Thermoset powder coats account for over 90% of the powder coating market, having a total market volume of 122 million pounds in 1991 [3]. Thermoplastic powder coatings are applied as thicker coatings for extreme performance properties and 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. In recent years, significant gains have been made in thermoset powder coating chemistry. As a result the thermoplastic market has been dwindling, as replacement thermoset powder coatings have been introduced. Currently, the thermoplastic market is fairly stable, holding a very specialized niche in the powder coating market, and is expected to maintain its current industrial market.

The majority of powder coatings (90 to 95%) are manufactured by melt-blend processing. Most industry representatives quote the high end of this range, so it is assumed that 93% of the total powder market is manufactured by melt-blending techniques, and the remaining 7% is manufactured by dry-blending processes. Nearly 100% of the thermoset powder coats are manufactured by melt-blending techniques. Based on the assumption of 7% (9.3 million pounds) market share for dry blending, and the breakdown of market shares according to resin chemistry, 19% (2.2 million pounds) of the thermoplastic powder market is manufactured by melt blending and 81% (9.3 million pounds) of the thermoplastic powder market is manufactured by dry-blending processes.

Process Description

The manufacture of powder coatings by melt blending, as shown in the flow diagram (Figure 1), consists of six basic processes [7]:

1. weighing of the raw materials
2. pre-mixing or dry-blending of the raw materials into a homogeneous dry mix
3. melt mixing of the dry blend into a single-phase continuous melt
4. cooling and flaking of the melt-mixed extrudate
5. grinding of the flaked extrudate into powder
6. sieving and classification of the powder product.

In steps 1 and 2 of the manufacturing process, raw materials are handled by the workers as the materials are weighed, transported, and loaded into the pre-mixing vessel. After pre-mixing, the contents of the vessel are fed directly into the extruder hopper. The dry materials are screw-fed into the extruder where they are kneaded and melted into a uniform melt.

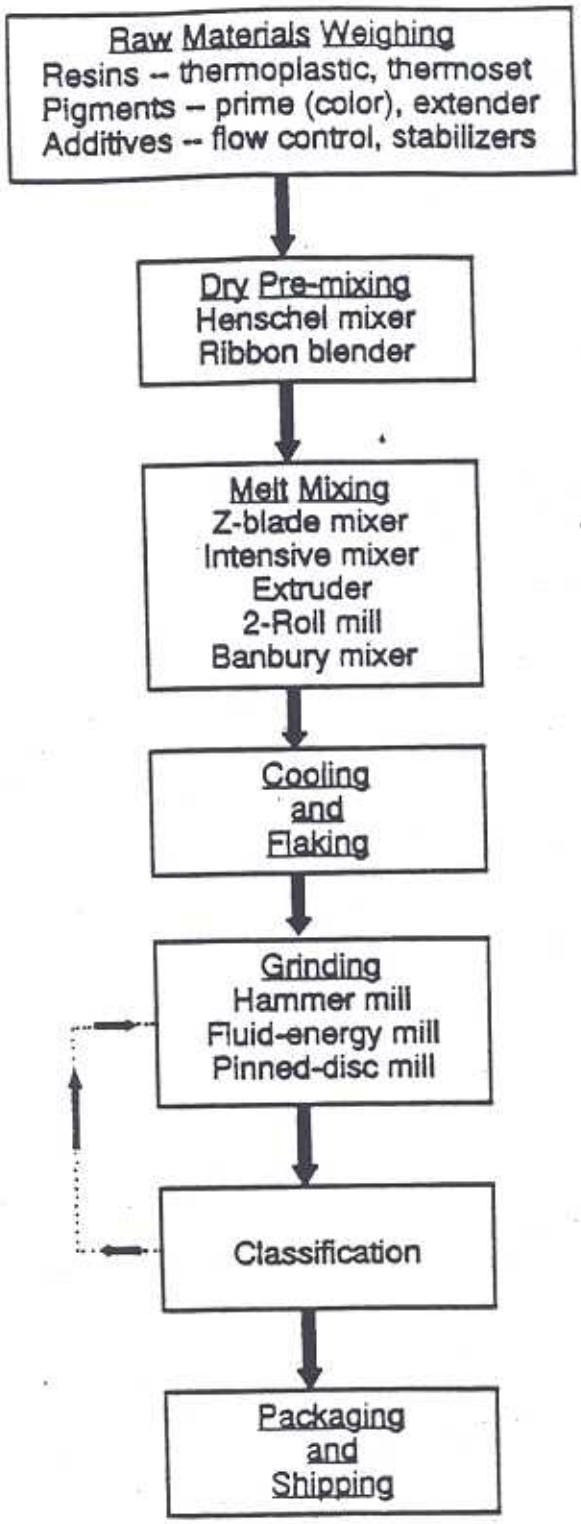

Figure 1. Flow diagram of melt-blend process for production of powder coatings

Because of binding or partial reaction with the resin, melt compounding reduces the threat of chemical reactivity from the raw components [8].

Reactive components such as isocyanates are present in the powder as blocked components. The high temperature of the curing oven unblocks these components so that crosslinking can occur. Due to the low temperatures of extrusion (ca. 190 to 290°F) and short residence times (30 to 60 seconds), no volatiles are emitted during the extrusion process [6,9]. The extrudate is pressed into ribbon form and cooled on a cold belt or drum prior to flaking. Solidification generally occurs in approximately 30 seconds.

The flakes are manually loaded into the grinders. Grinding and classification generally are performed in one process in air classifier mills. The specific gravity of the powder product may range between 1.2 to 1.8, with 1.6 being a typical value. Large particles are sieved out and reground. The resulting powder product typically is fed into 50-pound boxes for shipping.

Composition

Thermoset powder coatings typically are low-molecular-weight resins applied by electrostatic spray processes and cured at elevated temperatures. Table 1 shows the five major types of thermoset powder coatings [1]:

Table 1. Major Types of Thermoset Powder Coatings

Resin Type	Market Share
epoxy	29%
epoxy/polyester hybrids	17%
TGIC polyesters	21%
polyurethanes – polyester and acrylic	32%
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 [10]. Once cured, the coating will not flow upon reheating. Raw materials are 100% dry solids. Raw resin materials typically are in pellet form; the remaining raw components usually are powders. A typical thermoset powder formulation consists of the following:

- 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 [11].

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 for certain applications. Thermoplastic powders manufactured by melt blending are applied by electrostatic spray. Thermoplastic powders for application by fluidized-bed techniques are dry blended. Among thermoplastic powders, 65% of the nylon, 98% of the polyethylene and polypropylene, and all of the thermoplastic polyester, fluoropolymer, and polyphenylene sulfide thermoplastic powders typically are manufactured by melt blending [4,5,9].

Thermoplastic powders 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. A typical thermoplastic powder coating consists of the following:

- 60 to 70% resin
- 26 to 38% fillers and pigments
- 2 to 5% levelers and processing aids.

Currently, 38 facilities in the USA manufacture powder coatings. The larger facilities account for the production of 70 to 80% of the total market volume [3,6], and 60 to 80% of all powder coatings are produced for a specific client and intended for use in a specific application. As such production, even at a given facility, may vary widely, depending on the specific type of powder being produced, the volume of powder being manufactured for a client (batch size), the speed of the extruders melt mixing the raw materials, and the number of lines (extruders) being run.

The average large facility will run 2 shifts of 25 to 30 people operating 5 to 8 extrusion lines. Average extrusion rates are 700 to 1,000 pounds per hour, but higher rates of production (1,500 to 2,000 lb/h) are possible. Powder production lines are designed to extruder throughput capabilities, so production rate is directly related to the processing rate of the extruders. Due to processing variability and the wide distribution of plant capacities, for these calculations it is assumed that there are 12 facilities, each producing at a rate of 11 million pounds of powder per year. This assumption reflects the industry's mean production rate and is representative of the annual yield of the major powder producers, as well as the gross production of powder during 1991. The top three companies manufacturing powder coatings have the capacity to exceed this rate of production, and approximately 20 smaller facilities produce at lower rates.

Production Waste Generation, Environmental Releases, and Exposure-Level Calculations

Waste Generation

Conversion of raw material to powder product is in the range of 96 to 99% by weight. On average, waste can be assumed as 2.5 wt% of the final product, with 1.5 wt% occurring during grinding and classifying, and 1 wt% occurring during the rest of the manufacturing process. Of the 1 wt% waste generated prior to grinding, less than 0.1 wt% is waste generated before melt mixing; the remainder of this portion of the waste can be assumed to be generated during cleaning of the extruder, and, as such, to be in the form of a solidified melt mix that can be disposed of as ordinary nonhazardous solid waste.

Powders processed by melt-blend techniques typically are ground to 25 to 40 microns in size. Fines (particulates less than 10 microns) are separated out and disposed of as waste. It is assumed that the 1.5 wt% waste generated during grinding is all fines. This material, as well as the 0.1 wt% raw component powders, is dust and must be disposed of according to Occupational Safety and Health Act (OSHA) Worker Exposure Standards for Nuisance Dust. Nuisance dust is defined as particles of a size that could present worker exposure hazard in the air even though the particles had no toxic components. 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]. Generally, the powder waste is stored in containers on site until the waste containment area is full. At this time, the company contracted to perform the disposal is called to collect the containers. A trench is dug at the disposal site; the containers are collected, transferred to the site, placed in the trench, and covered. Containers may be bags or boxes of metal or plastic.

Assumptions

Unless otherwise given, the following is assumed:

- NS: number of sites, 12 each producing at 11 MMlb/year (22 MMkg/yr); for this calculation assume that only one powder type is produced
- PR: production rate of 800 pounds/hour
- H: 8-hour shifts,
- SH: 2 shifts per day
- DOP: 250 days of production per year
- L: 5 lines (extruders) per plant
- W: 25 to 30 workers per plant
- eff: plant operating at 70% (eff = 0.7) capacity/efficiency
- PMN: weight fraction of PMN material is given
- CR: concentration of respirable dust (5 mg/m^3)
- IR: inhalation rate (1.25 mg/h) [12]
- TR: number of times/day powder materials handled; one transfer results in exposure for the entire day

Environmental Releases (total lb/year)

Solids for Disposal: Assumed: 97.5% (by weight) conversion of raw materials to product: 2.5% total waste.

(a) Grinding and classifying: 1.5 wt% powder waste generated (fines); baghouse/filter efficiency of 99%

$$PR \times H \times SH \times L \times eff \times DOP \times NS \times 0.015 \times 0.99 \times PMN \times 0.454 \text{ kg/lb} = \underline{?\ \text{kg/year}}$$

(b) Pre-grinding processes: 1.0 wt% waste from rest of manufacturing processes: 10% of this is raw material waste from weighing and pre-mixing; will assume all raw material waste generated is in dry powder form.

$$PR \times H \times SH \times L \times eff \times DOP \times NS \times 0.01 \times 0.1 \times PMN \times 0.454 \text{ kg/lb} = \underline{?\ \text{kg/year}}$$

(c) Extruded waste material: 90% of this is extruded waste material in solid form.

$$PR \times H \times SH \times L \times eff \times DOP \times NS \times 0.01 \times 0.9 \times PMN \times 0.454 \text{ kg/lb} = \underline{?\ \text{kg/year}}$$

Total Solid Waste of PMN (kg/year) = (a) + (b) + (c)

Air Emissions: Assumed 1.5% powdered waste generated and air containing waste is passed through a baghouse/filter with efficiency of 99%; 1% loss of particulates (<1 micron) to air. Other: No off-gassing is assumed to occur during the melt-blending process. No incineration methods used to dispose of waste.

$$PR \times H \times SH \times L \times eff \times 0.015 \times 0.01 \times PMN \times 0.454 \text{ kg/lb} = \underline{?\ \text{kg/site/day}}$$

Water: None assumed. Water sometimes used in equipment cleaning, but concentration of particulate matter is assumed negligible. Water is assumed to be contained or processed to remove particulates.

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

Worker breakdown per manufacturing task based on industrial hygiene plant walk throughs can be assumed as follows:

- weighing of the raw materials (1 operator for 1 or two lines)
- premixing or dry blending of the raw materials into a homogeneous dry mix (1 operator per two lines)
- melt mixing of the dry blend into a single-phase continuous melt (1 operator per line)
- cooling and flaking of the melt mixed extrudate
- grinding of the flaked extrudate into powder
- sieving and classification of the powder product (2 operators per line for grinding, sieving, and packaging).

Due to the nature of the powders, all workers are assumed to be exposed to both a dermal and an inhalation hazard.

Exposure levels are determined for 1 worker, working one 8-hour shift in a given day. Worker exposure will be limited to tasks involving powder transfer from one vessel or stage of the manufacturing process to the next. Worker exposure time varies according to specific tasks and the number of time each worker has to perform these tasks during an 8-hour shift.

Inhalation Exposure: An inhalation rate of 1.25 m^3/hr or 10 m^3/day is assumed [12]. Powders are classified as nuisance dusts, with an overall permissible exposure limit (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. One exposure results in exposure for the entire day.

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

Dermal Exposure: Dermal exposure is limited to incidental exposure during materials handling of raw components, dry blended materials, melt-mixed materials, and finished product. Equations approximating exposure levels are based on data compiled on contact operations as given in CEB (1991, Table 4-13) [12]. One transfer would represent exposure for the entire day.

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

N transfer

Disposal Concerns

All powdered waste generated is disposed of in secondary containers and covered in a landfill. Solid extruder waste is disposed of in the same way. As 100% containment of materials cannot be assumed, behavior of the waste in a landfill may be of concern. Solubility and leach test data on the PMN material must be provided by the manufacturer submitting the PMN.

Solubility of raw materials: Refer to calculation (b).

Leaching from melt-blended materials (extrudate or powder waste): Refer to calculations (a) and (c).

References

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