

The background of the cover is a reddish-orange color. It features a faint, stylized illustration of a powder hopper or silo. Inside the hopper, there are numerous small white plus signs (+) and minus signs (-) representing static charges. Two jagged, lightning-bolt-like lines represent electrostatic discharge paths, one starting from the top and another from the bottom. The title 'Powder Handling and Electrostatics' is printed in a large, bold, black sans-serif font, centered horizontally. The subtitle 'Understanding and Preventing Hazards' is in a smaller, bold, white sans-serif font, also centered. The authors' names are at the bottom in a smaller, bold, black sans-serif font. There are three thick black horizontal bars: one above the title, one above the subtitle, and one above the authors' names.

# **Powder Handling and Electrostatics**

**Understanding  
and Preventing  
Hazards**

**Thomas B. Jones  
Jack L. King**

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## **Understanding and Preventing Hazards**

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## **PREFACE**

The subject of this manual is safe practice for the avoidance of electrostatic discharges (ESD) in the processing, bulking, and shipping of plastic powders and any materials used in their manufacture. It is written for practicing engineers and plant technicians who work in polymer processing or manufacturing facilities where plastic powders are used. Electrostatic discharges have been implicated in dust explosions that have occurred in plastics manufacturing operations at many locations throughout the world. Our objectives are to provide basic understanding of relevant electrostatic phenomena and practical guidelines for the reduction of ESD ignition risks to acceptable levels. The information in this manual is gleaned from our experience as well as published sources (over one hundred technical papers spanning forty years), technical standards (the National Fire Protection Association and the British Standards Institute), and innumerable written and oral communications with engineering, manufacturing and safety personnel.

Section I of this manual introduces the subject with a brief discussion of the probabilistic nature of electrostatic ignition hazards and its relationship to dust explosion hazards in general. Section II reviews relevant principles of electrostatics applied to bulked and flowing powders. Topics include charged powder phenomenology, charge separation and dissipation, and the identified types of electrostatic discharges. Basic electrostatic measurements and their practical interpretation are the subjects of Section III. Section IV provides

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## I. INTRODUCTION

The subject of this manual is the dust ignition hazards posed by electrostatic discharge (ESD) in the processing, bulking, and shipping of plastic powders and other materials used in their manufacture. The document is intended to provide engineers and other plant operations personnel with essential information concerning recommended safe practice for the minimization of these hazards. The airborne dusts of most polymers are known to be explosive [NFPA, 1976] and, furthermore, many of them are electrically insulating and triboelectrically active, suggesting that electrostatic ignition is specially important. Many plastics manufacturers have experienced dust explosions involving these materials. Chapter V describes a number of industrial incidents where electrostatic discharges have been implicated as the most likely ignition source. For these reasons, all plastics manufacturing firms must be committed to the design and construction of inherently safe manufacturing facilities and to their proper maintenance and operation. This commitment to abatement of ESD hazards is well-founded from the dual standpoints of worker safety and loss reduction.

Most dust ignitions may be traced to poor maintenance practice and carelessness: inadequate dust control, open flames, arcing in improperly protected electrical equipment, overheated bearings, etc. Overall, electrostatic discharges are thought to account for at most 10% of dust ignitions [Eichel, 1967], though this percentage may be much

higher in the manufacture and processing of insulating plastic powders because of the strong charging tendencies and charge retention characteristics of polymer materials. For example, a lighted match will much more easily ignite an explosive atmosphere of polymer dust than will an electrostatic spark from a person's fingertip. Despite the relatively low probability of ESD ignition, attention to abatement of such hazards is important because electrostatics is very hard to control; in some cases, routine measures are not sufficient to avoid exposure to significant ESD ignition risk. What makes the abatement of ESD ignition hazards especially challenging is the fact that some types of electrostatic discharges are beneficial (in that they help to dissipate accumulated charge) while others are quite dangerous (in that they can ignite flammable dusts).

### **Ignition probabilities**

Dust explosions involving plastics (including polyethylene, bisphenol-A, ABS, etc.) are not highly probable events. This is because several stringent conditions must be met simultaneously for deflagration to occur. The three requirements for a dust explosion are fuel, an oxidizing agent, and an ignition source [Bartknecht, 1987]. Dust is flammable or explosive only under a limited range of particle concentration values with the correct range of particle sizes and the correct oxygen concentration [Hertzberg et al., 1982]. Furthermore, the energy of the ignition source must exceed some minimum value intrinsic



to the dust and must possess the correct temporal characteristics and spatial localization. Loss prevention specialists find that the best way to quantify and predict dust explosion risks is to use probability measures. The overall probability of an explosion  $P_{\text{explosion}}$  may be expressed as the product of two separate probabilities [Schön, 1982].

$$P_{\text{explosion}} = P_{f/a} P_i \quad (1)$$

where  $P_{f/a}$  = probability of existence of flammable dust/air mixture and  $P_i$  = probability of simultaneous presence of adequate ignition source. By formulating the explosion probability in this way, the ESD ignition risk, measured by  $P_i$ , can be viewed in isolation from other factors.

Many electrostatic sparks can occur in an explosive atmosphere without causing an ignition. This is because, in addition to the minimum spark energy requirements for ignition, stringent conditions on the time dependence of the current flow in the spark and its spatial extent must be met. These conditions are not well-understood. A recent trend in electrostatic hazards research is the presentation of results in the form of ignition probabilities as a function of charge levels, voltages, and other electrostatic parameters for varied fuel/air mixtures, temperatures, etc. The paper by Gibson and Harper [1988] is in the vanguard of a trend toward probabilistic analyses that eventually will provide better guidance in making decisions about the abatement of ESD ignition hazards.

## II. ELECTROSTATICS IN PLASTIC POWDER PROCESSING

To grasp the basic problem of electrostatic hazards in the processing of powders, a fairly simple picture of what happens when powder is transferred from one container to another may be employed. Refer to Figure 1 which depicts powder being transferred pneumatically from a storage silo into a vessel.

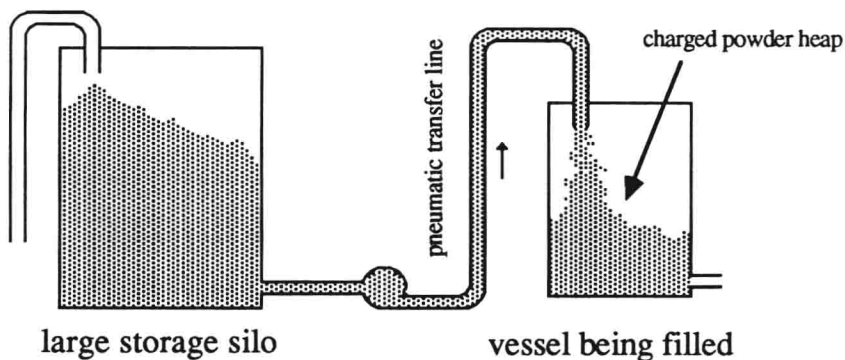


Figure 1. Typical transfer operation from large storage silo to smaller vessel. Powder becomes charged as it is pneumatically conveyed through transfer lines and this charge accumulates in the receiving vessel.

The powder becomes charged triboelectrically by frictional contacts of individual particles with the walls of the transfer piping. These particles, being highly insulating, tend to retain their charge for a long period. As charged powder fills the vessel, the electrostatic potential

and field within the heap and, more importantly, the electrostatic energy associated with the charge increase. The ignition hazard posed by charge accumulation is associated with the possibility that some portion of this electrostatic energy will be released rapidly within a small volume by an electrostatic spark and that this spark will be hot enough to ignite flammable dust that might be present. During filling, various mechanisms operate to counteract the buildup of charge: (i) *conduction*, where charge flows to the conducting walls of the vessel and is neutralized, and (ii) *corona* and/or *brush* discharges, where charge is neutralized by highly localized air breakdown and resulting ionization within the vessel. Conduction, corona, and brush discharges are ordinarily safe means by which dangerous charge levels in a vessel are either prevented from occurring or dissipated without incident.

A simplified representation of the various processes, due to Glor [1985], is shown in Figure 2. This figure depicts the separation and inflow of charge into the vessel, the dissipation of charge via conduction (the resistance to ground), and the possible sparking that can lead to ignition. Three important elements of powder electrostatics, evident in Glor's model, may be distinguished: charge separation, charge dissipation (including low energy discharges), and electrostatic discharge (capable of igniting dusts). Each of these elements is considered in a separate subsection below.

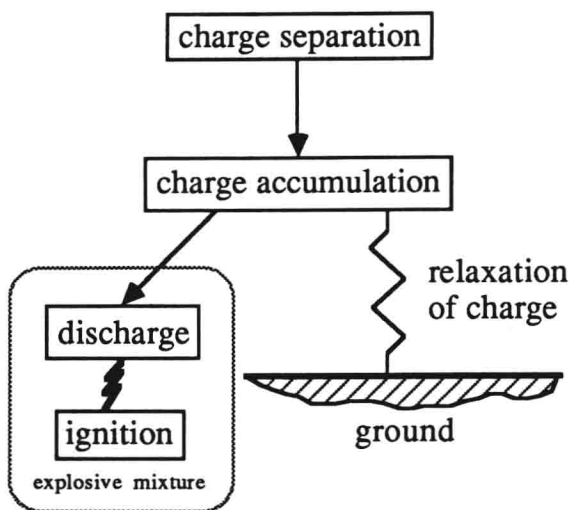


Figure 2. Glor's model for the accumulation and dissipation of electrostatic charge in a vessel being filled with charged powder [1985]. Any ESD hazard abates as the charge dissipates via charge relaxation or low-energy discharge (corona or brush discharge).

### A. Charge generation and separation

The generation of electrostatic charge in plastic powder processing is actually a separation of positive and negative charge. This charge separation is attributed to contact or frictional charging (known as *triboelectrification*), which occurs when materials of different electronic band structure (with differing electronic work functions) come into close mechanical contact. A listing of materials ordered according to their work functions is called a triboelectric series [Beach, 1964]. At

the boundary between two dissimilar materials, some of the electrons in the material with the lower work function are pulled across the interface and, when the materials are separated, this charge imbalance results in a net positive charge for one body and a negative net charge for the other body. For example, a contact between clean metal and polymer surfaces usually accumulates positive charge in the metal and negative charge in the polymer. Note that the physical separation of these bodies requires work, which becomes stored as electrostatic energy in the field. It is when this stored electrostatic energy is released in an electrical discharge that dust ignitions can occur.

Because of its crucial role in such important technologies as xerography, air filtration, mineral separation, and semiconductor device processing, triboelectrification has been the object of considerable scientific study. Despite this attention, it remains a poorly understood phenomenon. Most experimental investigations have focussed upon highly idealized cases, namely, flat, clean surfaces of pure substances. Serious investigations of triboelectrification in commercial materials and chemical compounds are often frustrated by the extreme difficulty of controlling factors such as surface contamination, water content, etc. In the case of plastic powders, triboelectrification studies are ordinarily confined to measurements of the relative charging tendencies of various important compounds.

Though a fundamental upper limit on powder charging is often referenced,\* more realistic estimates of the specific charge of powders can only be obtained from experimental measurement. Boschung and Glor [1980] have measured  $(q/m)$  for polymer plastic resins from  $10^{-1}$  to  $10^2 \mu\text{C/kg}$  using a small experimental rig that simulates pneumatic transport on a laboratory bench apparatus. These values are well below the limits predicted by Equation (3) because of the electrostatic discharges that inevitably occur when powders are bulked. Section A.2 of the Appendix contains practical specific charge data for six different powder processing operations. Of greatest interest in the manufacture of plastic resins are pouring, screw feeding, and pneumatic transport operations. Note that, of these three, pneumatic transport features the highest range of specific charge values,  $10^0$  to  $10^2 \mu\text{C/kg}$ . Specific

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\*...Charge resides on the surface of particles and so a fundamental upper limit for particle electrification may be derived by imposing the constraint that the electric field at the surface can not exceed the breakdown strength of air, i.e.,  $E_b \approx 30 \text{ kV/cm}$ . The limit upon charge per unit area  $\sigma_{\text{max}}$  (in Coulombs per square meter) is then

$$\sigma_{\text{max}} = \epsilon_0 E_b \approx 2.7 \cdot 10^{-5} \text{ C/m}^2 \quad (2)$$

where  $\epsilon_0 = 8.854 \cdot 10^{-12} \text{ F/m}$  is the permittivity of free space. Based on this notion of a maximum surface charge, a limiting value for the *specific charge*  $(q/m)_{\text{max}}$ , also called the charge per unit mass, for a spherical particle may be written.

$$(q/m)_{\text{max}} = 3 \sigma_{\text{max}} / R \rho \quad (3)$$

where  $\rho$  is the mass density of the particle (in  $\text{kg/m}^3$ ) and  $R$  is its radius (in meters). The limits predicted by Equation (3) are seldom achieved in practical situations. Refer to Section A.1 of the Appendix.

charge values in this range are sufficient to create a serious ESD ignition risk.

The picture of triboelectrification is further complicated by the observations of various workers who have found that not just the magnitude but the sign of the net charge seems to depend on particle size. It is commonly observed that fine particle of certain polymers charge negatively, while the coarser particles are charged positively [Lees et al., 1979]. The resulting charge separation, due to differential gravitational settling, dramatically influences the dynamic nature of the electrostatic field inside a vessel during and immediately after filling [Cross, 1980]. Humidity is also known to influence the magnitude and sign of triboelectrically charged powders.

## **B. Charge dissipation**

One mechanism by which the electrostatic charge accumulating in a powder heap may be safely dissipated is electronic conduction. If conduction is modeled as ohmic, then the well-known *charge relaxation* time  $\tau = \kappa \epsilon_0 \gamma$  (where  $\kappa$  is the *dielectric constant* and  $\gamma$  is the bulk *resistivity* in Ohm-meters) governs the rate of charge decay. As a general rule, powders with resistivity  $\gamma \leq \sim 10^7 \Omega\text{-m}$  have short relaxation times ( $\tau \leq \sim 10^{-3}$  seconds) and do not build up dangerous charge levels, while powders with  $\gamma \geq \sim 10^{13} \Omega\text{-m}$  have long relaxation times ( $\tau > \sim 10^2$  seconds) and must be regarded to pose significant ESD ignition risk [Boschung and Glor, 1980]. Materials with intermediate

values must be assessed on a case by case basis, taking into account all factors associated with the way they are handled. For typical polymers, such as polystyrene, polyethylene, etc., the relaxation time constant can range from  $\sim 10^4$  seconds for pure resin down to well below 1 second for some of the blends with high loadings of carbon black or certain other pigments and additives which promote charge relaxation. Humidity also strongly influences charge dissipation: relative humidities greater than approximately 60% usually reduce or eliminate static hazards.

### Circuit models

The physical significance of the time constant  $\tau$  may be grasped readily by considering the simple two-layer *capacitor* illustrated in Figure 3a. The layer of powder with resistivity  $\gamma$  and dielectric constant  $\kappa$  has a uniform initial volume charge  $\rho_o$  (in Coulombs/m<sup>3</sup>) which decays at all points within the layer according to an exponential law:  $\rho_{\text{volume}}(t) = \rho_o \exp(-t/\tau)$ . Part of this charge flows directly to the grounded electrode at the bottom while the rest accumulates temporarily at the powder/air interface. This surface charge then decays away slowly in accordance with the circuit time constant given by  $\tau_{\text{ckt}} = (C_{\text{powder}} + C_{\text{air}})R_{\text{powder}}$ , as defined by the circuit model shown in Figure 3b [Jones, 1987].



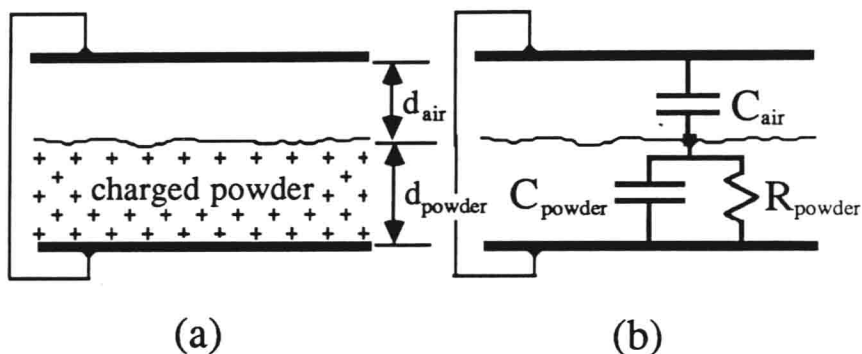


Figure 3. (a) Charged layer of powder between two grounded conducting plates. The powder has dielectric constant  $\kappa$  and resistivity  $\gamma$ . (b) Equivalent circuit for powder layer:  $R_{\text{powder}} = \gamma d_{\text{powder}}/A$ ,  $C_{\text{powder}} = A/\kappa\epsilon_0 d_{\text{powder}}$ , and  $C_{\text{air}} = A/\epsilon_0 d_{\text{air}}$ , where  $A$  is the plate area.

Note that the extrinsic circuit time constant  $\tau_{\text{ckt}}$  depends on the geometry and is always greater than the intrinsic charge relaxation time  $\tau$  [Jones and Chan, 1989a]. Therefore, the *residence time* for charge in any partially filled vessel is always greater than  $\tau$ . In most cases,  $\tau_{\text{ckt}} \approx \tau$ , but for a vessel nearly full or containing an insulating liner,  $\tau_{\text{ckt}} \gg \tau$  [Jones and Chan, 1989b]. This result indicates that the time duration of an existing ESD ignition hazard in a vessel can be much longer than the intrinsic charge relaxation time of the powder.

Another type of circuit model may be employed to establish the likelihood of a hazard when charge is being accumulated by a conductive object. Here, the approach is to determine if charge builds up to hazardous levels faster than any operative dissipation mechanisms can eliminate it. Consider the realistic situation of an ungrounded metal