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Influence of particle wall adhesion on particle electrification in mixers

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Abstract

In this work, particle electrification in the Turbula and horizontally oscillating mixers were investigated for adipic acid, microcrystalline cellulose (MCC), and glycine particles. MCC and glycine particles acquired positive electrostatic charges, while adipic acid particles attained negative charges in both mixers. Adipic acid (of sieved size larger than 500 μm), MCC, and glycine particles were monotonically charged to saturated values, and had negligible wall adhesion. On the contrary, the adipic acid particles, both unsieved and sieved but of smaller sieved size fraction, exhibited very different charging kinetics in the horizontally oscillating mixer. These adipic acid particles firstly acquired charges up to a maximum value, and then the charges slowly reduced to a lower saturated value with increasing mixing time. Furthermore, these particles were found to adhere to the inner wall of the mixer, and the adhesion increased with mixing time. Surface specific charge densities for adipic acid particles were estimated based on particle size distribution, and were found to increase with particle mean diameters under the conditions investigated. The results obtained from the current work suggested that electrostatic force enhanced particle–wall adhesion, and the adhered particles can have a significant impact on particle electrification.

Keywords: Electrification; Adhesion; Mixer; Kinetics; Charge

1. Introduction

Electrostatic charges can be generated when two different materials are brought together and then separated (Harper, 1967). Particles can be charged when they are processed in gaseous environments. Particle electrification is commonly a nuisance and may cause dust explosions (Joseph and Klinzing, 1983; Jones, 1995). On the other hand, particle electrostatic charges can also be exploited for example in powder flow measurement (Masuda et al., 1998; Rosales et al., 2002), powder separation (Yanar and Kwetkus, 1995), electrophotography in photocopiers and laser printers, and dry powder coating (Kleber and Makin, 1998). For the safe operation of particle handling systems and optimization of the performance of particulate systems, it is of great importance to understand the particle electrification behavior in particle processing systems.

The mechanism for contact electrification is not well understood especially for electrification involving insulators. Diaz and Fenzel-Alexander (1993) presented an ion transfer model to described contact charging between polymer containing ions and another polymer or metal, and they suggested that the sign and magnitude of the charge depended on ion content in the surface region of the polymer, the relative mobilities of the two ions in the salt, and the relative stabilities of the two ions on each of the two surfaces in contact. Diaz and Felix-Navarro (2004) constructed a semi-quantitative tribo-electric series for polymer materials by combining data from literature with their quantitative charging results with metal contacts. In addition to ion transfer model, electron transfer mechanism has also been proposed to explain insulator metal charging systems. Castle and Schein (1995) suggested a surface state model (one of the electron transfer models) for the toner-carrier charging experiments and showed that majority of the data agreed with this model. Yu and Watson (2001) proposed a two-step electron transfer model to explain charging accumulation processes, namely contact of two surfaces and their separation. According to this model, interface states were formed and electrons from both surfaces were

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Nomenclature

A	particle surface area (m^2)
d	particle diameter (m)
f	frequency
k	elasticity parameter (Pa^{-1})
k_c, k_0, k_r	constants
M	total mass (kg)
n	number of contacts
N	number of particles
p	number-based particle size distribution function (−)
q	single particle charge (C)
Q	total charge (C)
S	contact area (m^2)
t	time (s)
T	charge mass ratio (C/g)
v_i	particle impact velocity (m/s)
Z_0	gap between contact body (m)

Greek letters

ε	relative permittivity of air
ε_0	permittivity of vacuum ($C^2\,N^{-1}\,m^{-2}$)
θ	particle wall coverage
ρ	particle density (kg/m^3)
σ	surface specific density (C/m^2)
τ	time constant (s)
ϕ	contact potential difference (V)

distributed in this interface states when the contact was established. These electrons would redistribute during separation before the interface states were eliminated. This electron redistribution led the insulator to be negatively or positively charged depending on more or fewer electrons being transferred to the insulator. The charging continued via the two-step process until the equilibrium was reached. Clint and Dunstan (2001) showed that there was a good correlation between the electron-donor surface tension parameter and the position of the solid in the tribo-electric series, and they believed that contacting charging was due to the transfer of electrons rather than ions. Lee (1994) proposed a dual mechanism of contact electrification for metal-insulator system, which included both ion and electron charge transfer. How and why charge transfers are not known exactly (Matsusyama and Yamamoto, 2006). A simple condenser model has been commonly used in the discussion of powder electrification (Matsusyama and Yamamoto, 2006; Matsusaka et al., 2000; Masuda et al., 1976).

Many naturally observed phenomena such as radio noise, light emission, and singing/booming sands may be attributed to the electrical charges generated on naturally occurring particles in sand, silt and dust during transport (Kanagy and Mann, 1994). These generated electric charges may in turn greatly influence on the transport and deposition behavior of sand and slits (Zheng et al., 2003; Kanagy and Mann, 1994; Zheng et al., 2006). In the chemical and pharmaceutical industry, particle electrification has been associated with solid handling processes such as in the powder pneumatic conveying (Kanazawa et al., 1995; Zhu et al., 2004), gas–solid fluidized bed (Chen et al., 2003; Rasanen et al., 2004), melt agglomeration process (Eliasen et al., 1999), and inhalation device (Dubus et al., 2003; Kwok et al., 2005). Electrostatic charges can greatly alter the particle flow dynamics and, hence, the system performance. Electrostatic charges generated in a pneumatic conveying line were found to result in solid granules sticking to the wall of the conveying pipe and forming stationary capsule annular films (Zhu et al., 2004). The presence of electrostatic charges in a gas phase fluidized bed polymerization reactor influenced the reactor hydrodynamics such as bubble characteristics and particle mixing behavior, and the resultant electrostatic force eventually led to the formation of the wall sheet, which resulted in plugging of the reactor product discharge system or loss of fluidization (Hendrickson, 2006). Guardiola et al. (1996) investigated the influence of particle size, fluidization velocity, and relative humidity on the electrostatic charge generation and accumulation in a fluidized bed by means of potential difference using an electrical probe. They found that the degree of particle electrification increased with particle size and air velocity. They also pointed out that the effect of relative humidity on electrostatic charge was complex and depended on the quality of fluidization. The aforementioned studies suggested that, as a result of particle–particle and particle–wall collisions, particles were always charged in the handling system, and these electrostatic charges greatly influenced the performance of the handling system and subsequent processes involving these charged particles. However, most of the previous work has focused on particle electrification in gas–solid two-phase flows.

Byron et al. (1997) measured the fine powder dose charge (FPD charge) of aerosolized drug and lactose particles from Turbohaler™ and Dryhaler™. Their results suggested that the charge level of fine particle dose was too large to be neglected, and the electrostatic charge would not only affect the total and regional deposition in the human lung but also influence the aerosol dispersion behavior in the air stream. Kulvanich and Stewart (1987) explored the influence of storage time on the total adhesion force of drug-carrier interactive systems at the relative humidity of 33%. Their results showed that total adhesion force decreased with storage time up to 23 days, and they attributed the decrease of adhesion force to the decay of electrostatic charges. Influence of electrostatic charges on the amount of particle respiratory fraction was also demonstrated by Philip et al. (1997). These studies highlighted the importance of electrostatic charges in the inhalation drug delivery systems. The electrostatic charge not only affected the aerosol dispersion efficiency, but can also influenced the drug deposition behavior in the lung as well.

Mixing of particles is important in many pharmaceutical operations. In many situations, a better mixing process could tremendously increase the quality of product. In the formulation of dry powder inhalation product, mixing is regarded as a key process for preparing fine drug particles with coarse carrier particles to form a homogeneous mixture. Even the sequence of