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Review

Electrostatic powder coating: Principles and pharmaceutical applications

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ABSTRACT

A majority of pharmaceutical powders are insulating materials that have a tendency to accumulate charge. This phenomenon has contributed to safety hazards and issues during powder handling and processing. However, increased understanding of this occurrence has led to greater understanding and control of processing and product performance. More recently, the charging of pharmaceutical powders has been employed to adopt electrostatic powder coating as a pharmaceutical process. Electrostatic powder coating is a mature technology used in the finishing industry and much of that knowledge applies to its use in pharmaceutical applications. This review will serve to summarize the principles of electrostatic powder coating and highlight some of the research conducted on its use for the preparation of pharmaceutical dosage forms.

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1. Introduction

The concept of electrostatic coating was recognized in the 1930s and 1940s (Pugh, 1932; Ransburg and Green, 1941). Electrostatic coating involves the charging of particles, spraying or atomization of the charged particles, and the deposition of the charged particle onto a grounded substrate. The deposited particles are then cured, usually by heat, to produce a film. The benefits of electrostatic powder coating include the ability to coat without the use of solvents, organic or aqueous. The use of organics solvents is undesirable from an environmental and operating cost standpoint, as handling and collection systems must be in place to avoid exposure to operators and release of volatiles into the environment. The use of aqueous solutions or suspensions usually requires longer processing times and high-energy consumption due the slow drying rate of water (enthalpy of vaporization: 40.65 kJ/mol). Additionally, it was found that transfer efficiencies of the electrostatic powder coating process were greater than seen with conventional liquid spray coating or dry powder fluidized bed processes (Misev and van der Linde, 1998; Wicks et al., 2007).

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Electrostatic powder coating also yields higher transfer efficiencies when compared to dry powder coating without utilizing electrostatic charge (or nonelectrostatic powder coating); generally 20% higher transfer efficiencies are seen with the application of 40–100 kV charging voltage, with these efficiencies increasing with decreasing particle size of coating material (Ratanatriwong and Barringer, 2007; Yousuf and Barringer, 2007). In addition to greater than 80–90% transfer efficiencies reported with electrostatic powder coating, recycling systems have allowed for 100% recovery of coating powder, further decreasing manufacturing waste (O'Neill and Bright, 1978; Sims et al., 2001). Increasingly strict environmental laws limiting volatile organic compound (VOC) emissions from coating solvents led to the rapid adoption of this technology by the metal finishing industry, both in Europe and the USA, in the 1960s and early 1970s (Castle, 2011; Wicks et al., 2007). Continued efforts for more environmentally friendly and energy efficient processes in other industries lead to use of this technology to treat electronics, plastic, and wood products and has even been adapted for use in food processing (Barringer and Sumonsiri, 2015).

More recently, electrostatic powder coating has been investigated for use in pharmaceutical manufacturing (Sauer et al., 2013). As many pharmaceutical powders are classified as insulating materials, they are amenable to charge accumulation with slow charge decay, making them suitable for use with electrostatic powder coating (Watanabe et al., 2007). Dry powder coating in pharmaceutical processing can be advantageous for manufacturing without the need for solvents, particularly when processing moisture sensitive active pharmaceutical ingredients (APIs) or biologics. It also eliminates the need for microbial testing of coating solutions/suspensions and reduces processing times and energy consumption, thus reducing operating costs. Electrostatic powder coating has also been shown to increase dry powder coating efficiencies, reported as higher coating levels obtained during tablet coating when compared to dry powder coating without applied voltage (Qiao et al., 2010b). The higher transfer efficiencies of electrostatic powder coating make this technique attractive to move towards more environmentally friendly and energy efficient dry powder coating of pharmaceuticals. This review will summarize the principles of electrostatic powder coating and highlight some of the applications of electrostatic powder coating to prepare pharmaceutical dosage forms.

2. Electrostatic powder coating

Coatings utilized by the finishing industry are primarily formulated to prevent corrosion of metals, especially in environments of extreme heat and/or moisture (Wicks et al., 2007). The cost savings due to the increased efficiency and reduced processing times, as well as the environmentally and regulatory friendly operation provided by electrostatic coating is invaluable. Over the last 40–50 years, development efforts continued to address other coating challenges, such as the ability to produce semi-conductive and corrosion resistant coatings for electronics (Radhakrishnan et al., 2009), improve temperature resistance (Kiefer, 2004), further increase efficiencies (Weiss, 1997), and enhance the appearance of the coating layer for aesthetic purposes (Meng, 2009). The technique was further advanced for the treatment of other substrates, such as wood, plastic and even paper (Barletta and Gisario, 2009; Cazaux, 2007; Mazumder et al., 2006). Due to the broad application of this technology, there is a significant amount of knowledge surrounding the utilization of electrostatic powder coating. This section will serve to summarize the principles of electrostatic powder coating, specifically the mechanisms of electrostatic charging, film formation, and adhesion of the film to the substrate.

2.1. Principles of electrostatics

Particles can be charged by two mechanisms: triboelectric or corona charging. Triboelectric charging describes charge accumulation due to friction. "Tribo-' is derived from Greek meaning "to rub'. This mechanism of charging results from the contact or rubbing of two dissimilar surfaces, the transfer of electrons from one surface to the other followed by the separation of the two surfaces, resulting in oppositely charged surfaces or charge separation. Triboelectrification is the primary mechanism of

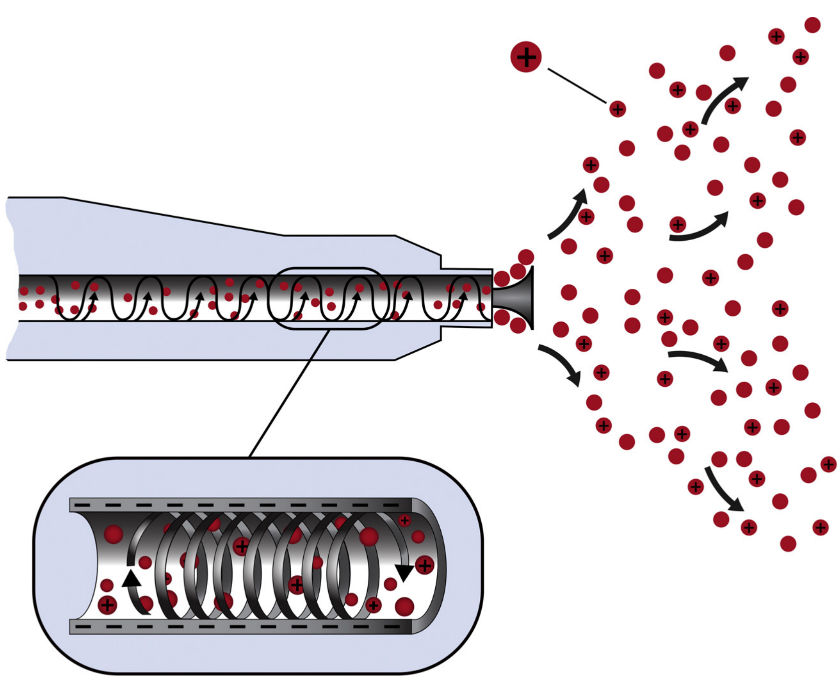

Fig. 1. Schematic of triboelectric gun designed to facilitate maximum particle to gun wall collisions (shown in inset).