International Journal of Pharmaceutics 441 (2013) 781–789

Contents lists available at SciVerse ScienceDirect

International Journal of Pharmaceutics

journal homepage: www.elsevier.com/locate/ijpharm

A novel sensing technique for measurement of magnitude and polarity of electrostatic charge distribution across individual particles

Tariq Hussain[a], Waseem Kaialy[b,c,*], Tong Deng[a], Mike S.A. Bradley[a], Ali Nokhodchi[b,d], David Armour-Chélu[a]

[a] The Wolfson Centre for Bulk Solids Handling Technology, Medway School of Engineering, University of Greenwich, Medway Campus, Chatham Maritime, Kent, UK
[b] Chemistry and Drug Delivery Group, Medway School of Pharmacy, University of Kent, ME4 4TB Kent, UK
[c] Pharmaceutics and Pharmaceutical Technology Department, University of Damascus, Syria
[d] Drug Applied Research Center and Faculty of Pharmacy, Tabriz University of Medical Sciences, Iran

ARTICLE INFO

Article history:
Received 27 July 2012
Received in revised form
28 September 2012
Accepted 1 October 2012
Available online 11 October 2012

Keywords:
Electrostatic charge
Powder
Blending
Inductive sensor
Bipolar charge
Particulate material

ABSTRACT

Electrostatic charge is generated during powder handling due to particle–particle and particle–wall collisions, rubbing, sliding, and rolling. In case of bipolar charge generation, the electrostatic forces may significantly change the inner forces and increase powder adhesion and cause a serious problem in material handling process. Therefore, the knowledge of distribution of charge across the individual particles is helpful to identify the role of triboelectrification and the effects of various relevant variables especially change in the contact materials, environmental conditions during processing, etc. A novel approach based on inductive sensor has been developed to detect the either polarity of charged particle and to characterise the bipolar charge distribution in the population of particulate material. To achieve this, an amplification unit configured as a pure integrator and signal processing techniques has been used to de-noise and correct the baseline of signal and MATLAB algorithm developed for peak detection. The polarity of charged particles obtained by this method is calibrated with Faraday pail method and the results are promising. Experimental study has been carried out by using two distinct populations of oppositely charged particles (glass beads-PVC, olivine sand, and silica sand). The obtained results indicate that the method is able to detect the distribution of polarities of charged particles.

1. Introduction

Electrostatic charging of particles occurs because of triboelectrification arising from particle–particle and particle–surface collision, rolling, sliding and rubbing during industrial processes. Several mechanisms are believed to be involved during triboelectrification, which are still unclear (Rowley, 2001). Such charging may result in several problems including unwanted particle agglomeration, segregation (which both have detrimental influence on homogeneity of powder mixture; Pu et al., 2009), increased drug-carrier adhesion (Staniforth, 1995), poor powder aerosolization (Bailey et al., 1998; Hashish et al., 1998), material build-up on equipment, etc. Such an impact is felt most severely by pharmaceutical industrial applications and its final product. This is because pharmaceutical powders are very prone to electrostatic charge as, usually; most of them are dielectric materials with irregular shape and size, generally, less than 100 μm (Yurteri et al., 2002). The influences of electrostatic charging of pharmaceutical powders are significant because they affect their dispersion, transportation, and lung deposition characteristics (Elajnaf et al., 2006; Nokhodchi et al., 2011). In case, the particles acquire bipolar charge, in which the net positive charge nearly balances the net negative charge, yielding a net charge of the bulk powder that is very close to zero (Yurteri et al., 2002).

Electrostatic charge is dependent on several factors such as particle surface roughness (Eilbeck et al., 1999), particle size (Carter et al., 1998), particle surface resistivity (Sharma et al., 2001), and particle relative humidity (charge decreases with increasing RH) (Rowley and Mackin, 2003), contact surface resistivity (Paasi et al., 2001), type of contact surface (Des Rosiers Lachiver et al., 2006), particle motions and binary collisions (Liao et al., 2011). Indeed, both vibration and frequency of vibrating add significant influence on adding electrostatic charging on material (Liao et al., 2011). Prior knowledge of distribution of charge on polarity basis and charge to mass ratio measurement will help to identify the problems caused by powder charge accumulation and adhesion (Elajnaf et al., 2006).

Despite the large available number of charge measurement techniques and instruments that measure powder charge, none of them, to best of our knowledge, is without disadvantages and

---

* Corresponding author at: Chemistry and Drug Delivery Group, Medway School of Pharmacy, University of Kent, ME4 4TB Kent, UK. Tel.: +44 1634 202960; fax: +44 1634 883927.
E-mail addresses: waseemkaialy@hotmail.co.uk, waseemkaialy@gmail.com (W. Kaialy).

0378-5173/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ijpharm.2012.10.002

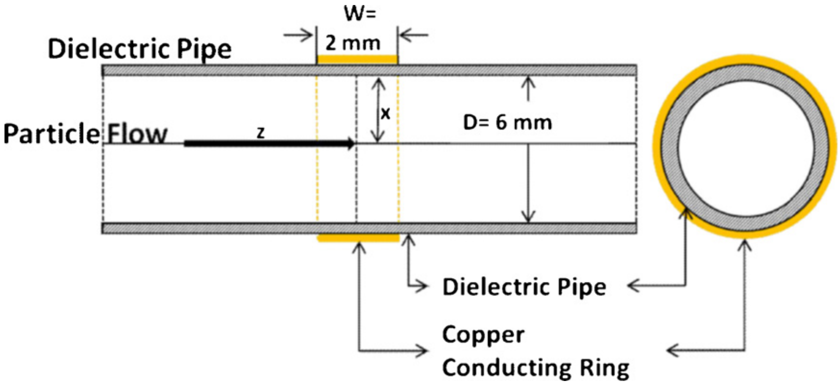

Fig. 1. Schematic showing the cross sectional view and optimised geometry of ring-shaped electrostatic inductive sensor.

practical limitations. Many existing charge measurement methods employ a similar approach in measurement principles but vary in data collection or data analysis techniques. A brief review for existing charge measurement methods has been presented by many researchers (Brown, 1997; Hoe et al., 2011; Kulon, 2003; Ose, 2001). Brown (1997) suggested dividing charge measurement methods into two categories based on measurement principles, namely 'static' and 'dynamic'. If a given method requires the particle's response to an external electric field it is then classified as "dynamic"; otherwise it is "static". Kulon (2003) further classified the dynamic methods into three categories: particle levitation techniques, mobility analysers and oscillatory field methods, whilst static methods were divided into two categories: contact and non-contact.

Dynamic methods for charge measurement, although accurate and capable of differentiating between polarities as well as measuring particle size, have the limitation of being laborious, difficult to use and cost effective (Kulon, 2003). For example, E-SPART analyzer electrostatic separator is professionally available and offers advantages in measuring both polarities of charges at the same time (Mountain et al., 2001; Mazumder et al., 1991). The bipolar charge measurement system (BCMS) offers an effective way to characterise bipolar charge (Kulon et al., 2001).

Static methods such as the capacitive sensor (Singh and Hearn, 1985) (ring-shaped, square-shaped, non-contact) inductive sensor (Armour-Chélu and Woodhead, 2002; Gajewski, 2008; Peng et al., 2001) (single, multi, or flow) Faraday pail contact and non-contact probes (Taylor, 2001; Ali et al., 1998; Zhao et al., 2003; Matsusaka and Masuda, 2006; Matsusaka et al., 2008) are all relatively simple, robust and easy to operate. Some researchers (Ali et al., 1998; Zhao et al., 2003) tried to use the multi Faraday pail methods in the form of cross laid and vertical array to characterise the material in terms of polarity, however, the presented results showed limitation in terms of repetition. Further research carried out to use the induction method for bipolar charge or to measure the charging tendencies of particulate material in pneumatic suspension (Armour-Chélu and Woodhead, 2002). Reported results highlighted the difficulty of data analysis, drifting of the signal and residual charge. Consequently, limited information may be obtained in the form of root mean square (RMS) value of signal or when clouds of particles are considered as a single charged particle.

In dry powder inhaler (DPI) field, there are many methods which are capable of measuring electrostatic charge carried by a DPI aerosol such as using a grid probe (Murtomaa et al., 2003), however this technique is considered less pertinent to pharmaceutical applications. Other technique includes DPI charge measurement by using the Faraday pail, however this technique is not capable of identifying different size fractions and charge distribution (Telko et al., 2007). Also, DPI electrostatics could be measured by using ELPITM which was more comprehensive, accurate, and capable to measure the magnitude and the polarity of the resulting currents (Telko et al., 2007).

To best of our knowledge, none of these methods allow an understanding of how the charge is distributed across the individual particles in terms of magnitude and polarity. In this paper, a novel approach is presented based on ring-shaped electrostatic inductive sensor to develop a bench scale charge measurement method to detect the bipolar charge distribution in population of particles. Signal processing (analogue and digital) techniques have used to filter the data acquired from the inductive sensor pre and post data acquisition to extract the signal of interest from noisy and baseline drifted raw data. Peak detection algorithm was developed in MATLAB environment to detect the positive and negative peaks from the filtered data and subsequently produced the charge distribution. The reported results in this paper have used optimised geometry of inductive sensor to achieve the better sensitivity and better resolution. Preliminary study shows that the method can be used to detect the bipolar charge distribution in population of large number of particles. Principally, triboelectric series arrange the different materials based on the work function to indicate the charge polarity when they triboelectrically charged with other materials. Different types of oppositely charged population of materials selected by considering triboelectric series, namely, glass beads–PVA1600 and olivine sand–silica sand were used in this study to test the performance of method.

2. Materials and methods

2.1. Materials

Test materials were chosen by considering the triboelectric series, which principally indicate the charging trend of different materials. Glass beads type S-1000 (size 1.3 mm) were provided by Silibeads, Germany whereas PVA1600 Poly (vinyl alcohol) hydrolysed powder ($D_{10\%} = 471\ \mu m$, $D_{50\%} = 655\ \mu m$, and $D_{90\%} = 719\ \mu m$) was purchased from Acros Organic, Belgium. Olivine sand ($(Mg,Fe)_2SiO_4$) ($D_{10\%} = 118\ \mu m$, $D_{50\%} = 169\ \mu m$, and $D_{90\%} = 206\ \mu m$) and silica sand (SiO_2) ($D_{10\%} = 116\ \mu m$, $D_{50\%} = 172\ \mu m$, and $D_{90\%} = 261\ \mu m$) were purchased from B&Q. Particle size of the latter materials was determined using laser diffraction (Kaialy et al., 2010a, 2011a).

2.2. Methods

2.2.1. Fundamental theory and experimental setup

The schematic diagram of the optimised geometry of electrostatic inductive sensor is presented in Fig. 1. The inductive