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Particle–particle coating in a cyclomix impact mixer

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ABSTRACT

Dry particle coating can be used to create new-generation materials by combining different powders exhibiting different physical and/or chemical properties. In such processes relatively large particles (host particles) are mechanically coated with fine particles (guest particles), without using solvents and subsequent drying, to create new functionalities or to improve initial characteristics. The coating of a host powder by guest particles can be performed in many different ways ranging from simple stirring of two components, to high energy impact coating.

The purpose here is to examine the use of a Cyclomix high shear mixer granulator for the surface modification of silica particles by dry coating with magnesium stearate, and of cornstarch dry coated with hydrophilic or hydrophobic fume silica. Several powder characterisation methods have been used to study the physico-chemical properties of the coated particles. These include: Observation by environmental scanning electron microscopy (ESEM), Characterization of cohesion and flowability by tap density measurements, Determination of wettability by measurements of the contact angle between the coated particles and water. Measurement of moisture adsorption-desorption isotherms of uncoated and coated particles, and Tribo-electrification characteristics of the powders. The results show that the surface properties of the two host particles are changed, and that the Cyclomix can be used for dry particle coating to modify the properties of silica gel and cornstarch powders.

1. Introduction

Dry particle coating can find application in many industries for changing the surface properties and/or functionality of powders. For example it may be used in the pharmaceutical, cosmetic, food or ceramics industries for modification of flowability, wettability (hydrophobic/hydrophilic properties), dispersability and rate of dissolution, flavour, particle shape, electrostatic, optical, electric, magnetic, particle properties. As indicated in Fig. 1, in such coating processes, powders with relatively large particle sizes (host particles: 1–500 µm) are mechanically coated with fine particles (guest particles: 0.1–50 µm) in order to create a new functionality or to improve their initial characteristics [1]. The success of the process depends on the “affinity” of the guest particle for the host particles and the mechanical forces brought to bring them together. Since the guest particles are very small, Van der Waals interactions are strong enough to keep them firmly attached to the large host particles [2]. Thus, either a discrete or continuous coating of guest particles can be achieved depending on the operating conditions such as mechanical force used, processing time, weight fraction of guest to host particles and particle properties [3]. Multiple layering is possible when using different coating materials and processing them one after other. Kangwantrakol et al. (2001) [4] have described a method to make multilayer coating of guest particles.

Dry particle coating is very closely related to ordered mixing (a term coined by Hersey, 1975), where a mixture is formed by covering the surface of larger particles with smaller particles. However in dry particle coating, the aim is to make the surface covering more permanent with stronger physical (or chemical) bonding [3]. Initial work on ordered mixing was done by Hersey [5]. The concept of ordered mixing was also taken one step further (to dry coating) by using dry impact blending, as described in a series of papers by a Japanese group [6–9]. Several different machines have been developed for dry coating allowing the creation of new types of materials. Most of the devices which have been used for dry powder coating are rather specialised laboratory type equipment and not readily available for processing amounts greater than several grams of powder. Pfeffer [3] gives descriptions of these different dry coating systems. Mujumbar et al. [10] have studied dry coating to enhance the moisture resistance of ground magnesium powder by coating its surface with carnuba wax using Magnetically Assisted Impaction Coating (MAIC) and two high-speed impaction devices, the Hybridizer and Mechanofusion device. Yang et al. [11] showed that it is possible to improve the flowability of cornstarch by coating with nanosized silica, using dry coating devices such as MAIC and Hybridizer.

Here we describe an experimental investigation of dry powder coating using a “Cyclomix” high shear mixer. This apparatus is a vertical cone shaped high shear mixer made by Hosokawa Micron and is

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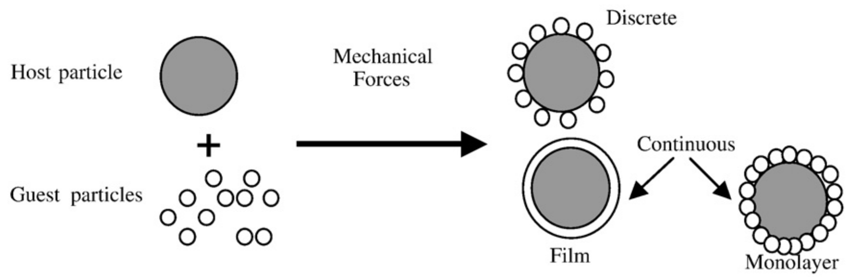

Fig. 1. Dry powder coating.

available in a range of sizes from 1 L to 500 L. Ng et al. [12] presented an experimental study on the solids motion in a Cyclomix by the positron emission particle tracking technique. Kwan et al [13] studied the granulation of hollow glass beads in a range of sizes of Cyclomix for scale-up. Here we report experiments which have been performed using a Cyclomix for mechanical dry coating of silica gel particles with magnesium stearate, and for coating starch particles with hydrophilic and hydrophobic fume silica. The effects of these surface coatings on the flowability, the wettability and tribo-charging are determined.

In a previous paper on dry particle coating [14] we presented an experimental technique based on dry powder particle size analysis for determining the force required to remove the coating layer. This allowed us to compare the mechanical resistance of coatings made using different techniques such as manual shaking, a Turbula mixer, and a Hybridizer. The advantage of the Cyclomix is that it can treat large quantities of powder and is available for industrial processing, and one of the aims of this paper is to evaluate the resistance of a Cyclomix coating with that made by a Hybridizer.

2. Experimental

2.1. Powders

Silica gel powder supplied by Merck and usually used for chromatography column has been chosen as host particles for dry coating. This silica gel has a hydrophilic porous structure which readily absorbs moisture and as shown in Fig. 3(a) the particles are irregularly shaped and their surface is rough. Hydrophobic magnesium stearate (MgSt) supplied by Chimiray is used as guest particles. The MgSt is a fine, white, greasy and cohesive powder widely used in pharmaceutical formulation as a lubricant. Observation by ESEM showed a wide distribution of size and shape including needle and plate like particles. The starch was Corn Starch B from Roquette Freres. The fumed silica was from Degussa; Aerosil R200 hydrophilic, Aerosil R974 hydrophobic. The properties of host and guest particles used in the experiments are summarized in Table 1.

2.2. Coating processes

The mass percentage of guest particles required in a coating experiment is calculated based on the assumption of 100% surface coverage of the host particles with a monolayer of guest particles. It is assumed that both host and guest particles are spherical (respective sizes D_{host} D_{guest}, respective densities $\rho_{\text{host}}\,\rho_{\text{guest}}$), and do not change shape during the coating process. Based on these assumptions, the mass percentage (W) of guest particles for 100% coverage can be written as [10]:

$$W(\%) = \frac{\left(ND^3_{\text{guest}}\rho_{\text{guest}}\right)}{\left(D^3_{\text{host}}\rho_{\text{host}}\right) + \left(ND^3_{\text{guest}}\rho_{\text{guest}}\right)} \times 100 \tag{1}$$

For $D_{\text{host}} \gg D_{\text{guest}}$ (here, $D_{\text{host}}/D_{\text{guest}} \approx 10$), the number N of guest particles per host particle is given by the expression:

$$N = \frac{4\left(D_{\text{host}} + D_{\text{guest}}\right)^2}{D^2_{\text{guest}}}. \tag{2}$$

From Eq. (1), the percentage of guest particles needed to coat silica gel particles is determined to be 15%. In addition, coating experiments have been carried out with 1% and 5% of magnesium stearate in order to compare what happens mass ratios of guest to host particles lower than 15%. The percentage of fume silica guest particles needed to coat starch particles is determined to be 1%.

A 1 L capacity Cyclomix (Hosokawa Micron B.V.) high impact mixer is used for the coating experiments. The mixer has four pairs of flat-bladed impellers located in series on a centrally located high-speed top driven rotating shaft. This eliminates seals and bearings from the product zone. The shaft is fitted with paddle-shaped mixing elements, which rotate close to the inner vessel wall [12]. Fig. 2 shows a schematic diagram of the action of a Cyclomix mixer. The working principle of the Cyclomix differs from existing mixing techniques and from other devices used for dry

Table 1
Properties of host and guest particles

Particles	Size d_{50} µm mastersizer	Solid density g/cm^3 HeliumPycnometer	Wetting characteristics	Specific surface (m^2/g) (ASAP 2010)
Silica gel	55	2.07	Hydrophilic	510
Cornstarch	13	1.47	Hydrophilic	–
Aerosil R200	0.12	2.27	Hydrophilic	200
Aerosil R974	0.12	2.27	Hydrophobic	174
MgSt	4.6	1.04	Hydrophobic	6

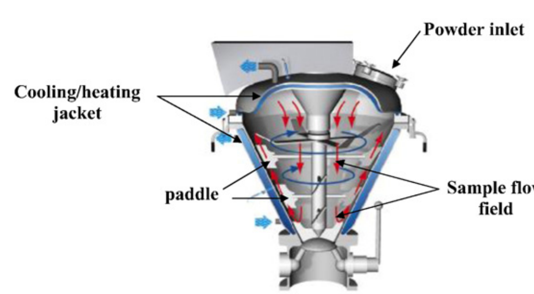

Fig. 2. Schematic diagram of a Cyclomix high shear mixer.