Powder Technology 215–216 (2012) 151–155

Contents lists available at SciVerse ScienceDirect

Powder Technology

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

Shear-assisted fluidized bed powder-coating

Piero Bareschino [a], Francesco Pepe [a], Piero Salatino [b,]*

[a] Dipartimento di Ingegneria, Università degli Studi del Sannio, Piazza Roma 21, 82100 Benevento, Italy
[b] Dipartimento di Ingegneria Chimica, Università degli Studi di Napoli Federico II, P.le Tecchio 80, 80125 Napoli, Italy

ARTICLE INFO

Article history:
Received 17 December 2010
Received in revised form 21 September 2011
Accepted 22 September 2011
Available online 1 October 2011

Keywords:
Fluidized bed
Powder coating
Shear

ABSTRACT

This study addresses a novel concept of dense-fluidized bed coating of objects where the effectiveness of coating is promoted by the intentional and controlled establishment of shear flow around the object. The fluidized powder is sheared by the controlled oscillatory motion of the object with respect to the fluidized bed. The proof-of-concept is given with experiments carried out using a commercial powder specifically manufactured for dry coating applications in fluidized bed. Systematic analysis of the effect of different levels of shear rate on particle mobility/adhesion and effectiveness of coverage was performed. A simple model has been developed to provide a mechanistic framework for the interpretation of the results.

1. Introduction

Painting or coating of an object may be conveniently carried out by dense-bed powder-coating, a process which consists of dipping the object into a dense expanded or bubbling fluidized bed of fine powders so as to favor cohesion or adhesion of the bed material onto the surface. Compared with alternative solvent- or emulsion-based processes, dry powder-coating usually entails a much lower environmental impact and possible savings associated with the use of dry powders. Fluidized dense-bed coating has several distinctive features, when compared with alternative dry-powder electrostatic spraying techniques, which may encourage its use. Among the positive features, one can recall a typically better powder transfer efficiency to the object's surface.

Fluidized bed coating can be accomplished either without or with the application of electrostatic fields [1]. In conventional fluidized bed coaters the object is dipped into the fluidized bed after pre-heating to a temperature slightly higher than melting or softening temperature of the coating powders. As the powder approaches the object surface, it softens or melts, forming a coating layer whose thickness increases with dip time. Electrostatic fields may induce additional clamping forces between the particles and the object that further stabilize the coating [2]. Accordingly, in the electrostatic-assisted fluidized bed coating process the powders (charged by the ionized fluidization medium) are attracted towards metallic objects that are at ground potential improving coverage and stability of the coating. One possible drawback of electrostatic-assisted fluidised bed coating is that the thickness and uniformity of the coating layer can be inadequate due to the presence of voids/pinholes on plain surfaces and/or poor coverage of inner angles, as reported in the literature [3]. Several authors [4–7] systematically investigated the influence of process parameters (e.g. substrate pre-treatments, preheating methods, superficial gas velocity, dipping time, applied voltage) and powder properties on coating thickness and uniformity.

In the present study the dense-bed powder coating of objects is analyzed with a focus on the effect that intentional promotion of shear flow of the fluidized powder may exert on the effectiveness of coating. The basic concept is that shearing the emulsion phase of the bed at an appropriate intensity should enhance particle mobility, overcoming cohesive forces and disrupting the cellular structure typical of the particulate expansion of beds of group-A powders [8]. The consequent augmented particle mobility should improve the uniformity and the effectiveness of coating.

Experiments have been carried out to obtain a preliminary proof-of-concept. To this end uncoated flat objects have been immersed in a dense fluidized bed of a commercial powder specifically formulated for fluidized-bed powder-coating applications. The novel feature of the experiments was represented by the fact that pre-set levels of shear rate at the surface of the object were induced by imposing oscillatory translational motion of the object itself of given amplitude and frequency. The effectiveness of coating was quantified by point-wise measurement of the reflectance of the coated surface as compared with that of the uncoated one. To this end an automated image analysis procedure was set up.

2. Experimental

2.1. Apparatus

The scheme of the experimental apparatus (not to scale) is reported in Fig. 1. It consists of a cylindrical fluidization column,

* Corresponding author. Tel.: +39 0817682258; fax: +39 0815936936.
E-mail address: salatino@unina.it (P. Salatino).

0032-5910/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.powtec.2011.09.040

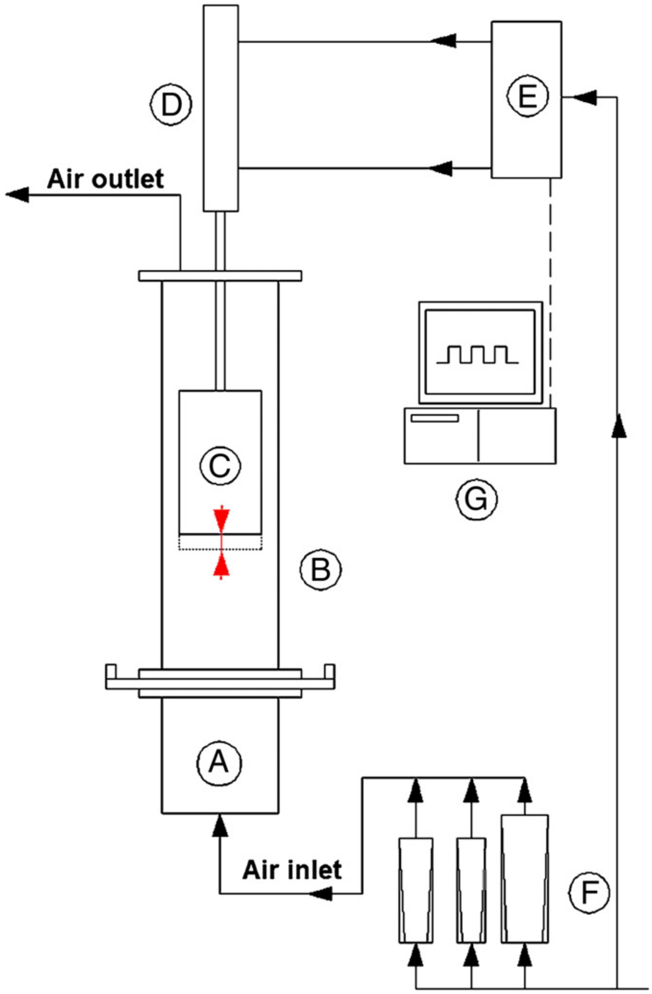

Fig. 1. Schematic view of experimental apparatus (not to scale): (A) wind box; (B) fluidized bed; (C) specimen; (D) pneumatic cylinder; (E) electrovalve; (F) flow controller; and (G) square wave generator.

120 mm I.D. and 280 mm high, made of Plexiglas® and equipped with a porous plate distributor. A vertical double-acting high-speed pneumatic cylinder was aligned with the column so that the specimen, a metallic sheet clamped to the shaft of the cylinder, could be immersed into the fluidized bed along its centerline. The cylinder is actuated by means of an electrovalve connected to a simple circuit generating a stable 12 V peak-to-peak square wave at a pre-set frequency in the range 0 to 4 Hz in order to establish sheared flow conditions around the object. Gas superficial velocity is measured and controlled by means of mass flow meters.

A highly light-sensitive mega-pixel CMOS camera (space resolution 4000 × 3000 pixel) interfaced with a computer and controlled with an image processing software was employed to record the experiments. Post processing of images acquired was accomplished to obtain quantitative evaluation of the effectiveness of coating.

Table 1
Properties of the granular systems investigated.

Sauter mean diameter (d_p), μm	20
Size range, μm	10–100
Particle density (ρ_s), kg/m^3	2800
Incipient fluidization velocity (U_{mf})[a], m/s	1.4 × 103
Terminal velocity (U_t)[b], m/s	3.0 × 102

[a] Measured.
[b] According to Haider and Levenspiel [9].

2.2. Materials

The fluidized bed consisted of a commercial powder specifically formulated for fluidized-bed powder-coating applications. The main properties of the powder are reported in Table 1.

The specimens were type 304 SAE stainless steel sheets of rectangular shape, about 8 cm × 20 cm and about 2 mm thick.

The fluidizing gas was technical air at ambient temperature. The gas superficial velocity was set at 2.1×10^{-3} m/s, that is 1.5 times the measured U_{mf} value.

2.3. Experimental procedure

The gas velocity was adjusted to its pre-set value. After a few minutes, needed to ensure steady and even fluidization of the solids, the specimen was dipped into the bed for half of its length. Subsequently, the square wave generator was activated at a pre-set frequency (F) in order to impose a vertical 1 cm amplitude oscillation (Δz) to the specimen. When the time elapsed, the sheet was extracted from the bed and image-analyzed. The total duration of a dipping cycle was 12 s, including 1 s to dip and 1 s to lift the piece out of the bed. No electrostatic field was established during the experiments.

The analysis of the acquired images was based on a MATLAB® procedure: an algorithm was developed to automate the process of measuring the gray intensity of individual pixels in a selected area of the image overlapping with the specimen, as shown in Fig. 2. The recorded data were worked out taking into account the stochastic nature of the local sample reflectance and expressed as cumulative frequency distribution (CFD) of the pixel gray intensity (or, equivalently, of the local sample reflectance). The value of gray intensity corresponding to the maximum of the CFD obtained from the analysis of a clean reference specimen was taken as the threshold between the coated and the non-coated regions of the specimen. The pointwise difference evaluated at the threshold between the values assumed by the CFD of the uncoated sample and that of a coated one is representative of the fractional coated area of the specimen.

3. Experimental results and discussion

3.1. Experimental results

Fig. 3 reports plots of the cumulative frequency distribution (CFD) of pixel gray intensities obtained in accordance with the image-analysis procedure. Plots refer to experiments in which the sample was subjected to oscillatory motion at frequencies ranging from 0 to 4 Hz. The average reflectance of the uncoated reference specimen corresponded to pixel gray intensity of nearly 100, whereas the fully covered sample displayed pixel gray intensity of 256. Based on analysis of the reference uncoated specimen, the threshold pixel gray intensity was set at 180 corresponding to the maximum reflectance of the uncoated surface. Values of CFD corresponding to the threshold for the various plots represent the uncoated fractional area of the sample for the given frequency of the oscillatory motion. The complement (100-CFD)% represent the coated fractional area, to be compared with the fractional area of the sample that was actually immersed in the bed during the coating stage that was nearly 50% for all the experiments.

Data in Fig. 3 were worked out to obtain the ratio between the fractional coated area of the sample and the fractional area of the specimen that was actually immersed in the bed. Results are reported in Fig. 4. It is noteworthy that the effectiveness of coating is a non-monotonic function of the frequency of the oscillatory motion of the specimen. The "quality" of coating was maximum at an optimal frequency of about 1 Hz: at this frequency the ratio of the coated to the immersed areas of the sample approached unity (0.98). This ratio decreases at frequencies lower or higher than the optimal value.