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Powder Technology 150 (2005) 155–167
POWDER TECHNOLOGY
www.elsevier.com/locate/powtec

Numerical simulations of ultrafine powder coating systems

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Received 17 March 2004; received in revised form 11 November 2004; accepted 7 January 2005

Abstract

Numerical simulations for gas–solid two-phase flows were conducted for an experimental coating booth and an industrial coating booth to study the effect of the coating powder size on the performance of the coating process. To optimize coating parameters, simulations were conducted for different coating parameters, such as the size of the coating part, the distance between the coating part and the spray gun, the air flow rate and particle flow rate from the spray gun, the position of the pattern adjust sleeve of the spray gun, and the electrostatic field, in order to increase the coating process efficiency and coating quality.

In numerical simulations, the air flow field is obtained by solving three-dimensional Navier–Stokes equations with standard κ–ε turbulence model and non-equilibrium wall function. The second phase, the coating powder, consists of spherical particles and is dispersed in the continuous phase, the air. In addition to solving transport equations for the air, the trajectories of the particles are calculated by solving the particle motion equations using Lagrangian method. It is assumed that the particle–particle interaction can be neglected due to low particle volume fraction in coating systems. The electrostatic field is predicted by solving the Laplace equation.

Keywords: Powder coating; Gas–solid two-phase flow; Numerical simulation; Lagrangian method; Eulerian method; Particle transfer efficiency; Turbulence model; Electrostatics

1. Introduction

Powder coating is environmentally friendly and more economical than liquid coating since it eliminates the problem associated with solvent emission, reduces the extra cost of solvent and allows easy recycle of over sprayed coating powder. While powder coatings have been applied mainly to low-end products in the past, such as underhood automobile components, a recent trend in the last decade of the 20th century is to expand their use to new markets where powder coating is not typically used. This includes automobile top coatings, can and coil coatings, wood coatings and coatings on plastics and paper [1]. The quality of powder coatings depends critically on the size of coating particles, with the quality of surface finish being enhanced with decreasing particle size. In current industrial applications, the average coating particle size is 35–60 μm, since smaller particles tend to agglomerate badly and therefore form powder clumps that cause powder flow problems and affect the coating quality. As a result of using large particles, however, the finished surface has obvious orange peel and other imperfections that prevent the use of powder coating from high-end products. In order to improve the coating quality and enhance the coating efficiency so that powder coating can be applied to high-end products such as automobile top coats, the mean diameter of the particle size must be lower than 20 μm. Ultrafine particles, if applied properly, can produce much more uniform coatings, resulting in superb coating finishes that cannot be achieved by regular sized (35–60 μm) coating powder. A recent invention [2] at this university has led to the smooth fluidization of ultrafine coating powders and this new technology has now been commercialized in Ontario,

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doi:10.1016/j.powtec.2005.01.005

Canada. Much superior coating quality and thinner coating film have been achieved on the production line, with finer paint powders.

Very few experimental studies and numerical simulations were conducted in the past with ultrafine powder coating. Sims et al. [3] conducted several experiments and suggested that the mean particle size has a dominant effect on the final coating appearance and the charging characteristics. Smaller particle sizes were found to give a more uniformly deposited powder layer and greater coating consistency while larger particle sizes usually acquire a bigger charge and are more efficiently deposited on the part. Finer particles also led to lower particle transfer efficiency (PTE). However, because their target (10×30 cm) is relatively small, the above conclusion may not be completely true. Because finer particles have a higher tendency to follow the gas flow to disperse laterally around the target than coarser particles, it is possible that a higher proportion of finer particles miss a smaller target than a larger target, giving lower PTE for finer particles. This should not be the case for a larger target.

Numerical simulations can provide detailed information on air velocity distributions and particle trajectories inside the coating booth as well as the particle transfer efficiency, and therefore can be used for parametric study to optimize the geometrical and operating parameters of coating systems to enhance coating efficiency and coating quality. Several studies involving mathematical modeling and numerical simulation of the electrostatic powder coating process have been performed to examine the influence of the electrostatic field on the spray pattern, without using ultrafine powders. It was found that the space charge tends to widen the deposition area. Ali et al. [4] conducted numerical simulations of coating particle trajectories in powder coating systems in combination with experimental studies on charge-to-mass ratio and particle size analyses. However, the numerical simulation of the fluid flow was not incorporated in their work. The fluid velocity was interpolated from experimental measurements of the total velocity at distributed points.

Bottner and Sommerfeld [5] conducted numerical simulations of powder coating systems based on the Eulerian–Lagrangian approach. In their study, the gas flow was calculated by solving the Reynolds-averaged Navier–Stokes equations with the κ–ε turbulence model. The Laplace equation was solved for the electrostatic field and the effect of the space charge to the electrostatic field was ignored. The image force was also neglected. The Lagrangian method was used for the prediction of the particle motion.

Ye et al. [6,7] presented numerical simulations of a powder coating system. A corona spray gun was utilized in their study. The renormalization group (RNG) κ–ε turbulence model was used to simulate the air flow from the spray gun to the coating booth. The Lagrangian frame of work was used to predict the particle movement. The interaction between the continuous phase and the particle phase was neglected. The initial position of the particle was randomly created inside the spray gun, assuming an initial particle velocity to be the same as the air flow velocity at the same location. For the simulation of the electrostatic field, the effect of the space charge was included and the Poisson′s equation was solved.

However, due to the complex geometry of the spray gun and the flow pattern of the air flow and particle movement inside the coating booth, no article can be found in the literature in which the whole process of the powder coating system was simulated for an actual coating booth. The objectives of this study are to develop a numerical procedure for the simulation of the complete powder coating process in actual coating systems to investigate the difference on the performance of a coating process using ultrafine powders and regular powders. The typical average particle sizes of 15 and 45 μm are used in this study to represent ultrafine powder and regular powder, respectively. The geometric shape of the spray gun is after a SureCoat Nordson gun, with a pattern adjust sleeve (PAS). A parametric study is carried out to determine the effect of the coating parameters, such as the size of the coating part, the distance between the coating part and the spray gun, the air flow rate and particle flow rate (loading) from the spray gun, the position of the PAS of the spray gun, and the electrostatic field, on the performance of the powder coating system. The influence of the air flow field, electrostatic field and turbulence dispersion on the particle trajectories are all considered in the simulation. Assuming the particle spray to be dilute, direct interaction between particles is neglected; however, the interaction between the particles and the continuous phase is included. The electrostatic powder coating process is simulated using FLUENT v.6 [8].

2. The experimental powder coating system

A typical powder coating process consists of a fluidized bed hopper, a powder transport line from the hopper to the spray gun, an electrostatic spray gun, a coating booth, the parts to be coated, and a curing oven. The powder coating process can be illustrated as.

Powder Fluidization in the Feed Hopper
↓
Powder Transport to the Spray Gun
↓
Powder Charging and Spraying by the Spray Gun
↓
Powder Deposition on Coating Parts in the Spray Booth
↓
Powder Curing in the Oven

During the operation, paint powder particles for coating are first fluidized and mixed with air in the fluidized bed hopper. These particles are pneumatically carried through a