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# Comparison of electrostatic fine powder coating and coarse powder coating by numerical simulations

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**Abstract**

Powder coating has several key advantages over liquid coating, and fine powder coating makes the surface finish quality comparable with liquid coating. This work reports on the numerical simulation of a fine powder-coating process in comparison with coarse powder coating, using a commercial computational fluid dynamic code, Fluent v6.1. The purpose of the study is to understand the gas and particle flow fields inside the coating booth for various operating conditions and the effect of reducing particle size on the coating process. The air and powder particle flows in a coating booth were modeled as a three-dimensional turbulent continuous gas flow with solid particles as a discrete phase. The continuous gas flow was calculated by solving the Navier–Stokes equations, including the standard $k$–$\varepsilon$ turbulence model with non-equilibrium wall function. The discrete phase was modeled based on the Lagrangian approach. In addition to drag force and gravity, the electrostatic force including the effect of space charge due to free ions was considered in the equation of motion and implemented using user-defined scalars and user-defined functions. The governing equations were solved using a second-order upwind scheme. This study demonstrates that the use of finer particles of size 15 μm or lower can give a very smooth and uniform surface finish, which may serve the requirement of automotive top-clear coating. This also provides useful information about optimum operating conditions such as the airflow rate, the applied external voltage and the powder-spray rate. The numerical model can also be used to optimize the gun-booth design for a better coating efficiency.


*Keywords:* Powder coating; Numerical simulation; Electrostatics; CFD; Powder transfer efficiency

## 1. Introduction

The concept of powder coating originated in the USA in 1950s [1], and significant growth has been achieved over the last two decades with potential to penetrate into new markets, where traditionally liquid painting is used, such as automotive clear top coatings, can and coil coatings, coatings for industrial wood, plastics and paper. The overriding trend or goal for powder-coating technology is to provide coatings at least equal in performance to liquid coatings without sacrificing ease of application and environmental advantages. The main advantages over liquid coating are the elimination of solvent emission (and thus negative environmental impact), the nearly complete recycle of overspraying and improved weatherability (exterior durability).

Due to the inability of powder coating to provide a very smooth and glossy finish surface, the applications of powder coating in the automobile industries have so far been limited to underbody and interior trim components, and to some exterior trim parts such as steel and aluminium car wheels. A vast automotive topcoat market awaits a viable powder-coating process. One of the reasons behind this is the use of 30 μm or bigger size "coarse" particles in the present coating processes. These Geldart Group A powders have excellent flow properties but also lead to inferior surface-coating quality, such as "orange peels". The use of the "fine" Geldart Group C powders, 10–20 μm in size, if properly fluidized, can produce a very smooth-coating surface. This enables powder coating to enter the big market of automotive clear top coating and

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other high-end surface-coating markets. The research team at the Powder Technology Research Centre at this university has developed a novel technique, which can effectively fluidize very fine Geldart Group C paint particles [2]. As part of the effort in developing the new fine-powder-coating technology, it is very important to understand the air and particle flow fields inside the coating booth and the effect of reducing particle size on the coating process.

Numerical simulation of the coating process can provide significant insight into the process and predict the effect of different operating parameters, such as airflow rate, powder spray rate, applied corona charge voltage, particle size, etc., on the first pass transfer efficiency (FPTE) and the coating quality. The FPTE, which is the ratio of the powder deposited on the coating target to the amount of powder injected from the powder spray gun, and the coating quality are two parameters generally used to measure the performance of a coating process. The primary goal of a coating application is to obtain high FPTE while meeting the aesthetic requirements.

The electrostatic field plays a very important role in powder coating. Elmoursi [3–4] presented a numerical model that can be used to determine the electrical characteristics of a bell-type electrostatic liquid painting system. In his study, the space charge due to the presence of free ions was taken into account. It was found that the space charge tends to increase the deposition field and also causes the spray pattern to expand. Ali et al. [5] developed a mathematical model to simulate single particle trajectories in the electrostatic field of a corona powder-coating system for a given charge-to-mass ratio, particle diameter and initial position. It was found that as the charge-to-mass ratio increased, the particle trajectory spread further out in the radial direction. Admiak [6] presented a numerical algorithm for simulating the electrostatic field distribution and particle trajectories in a tribo-charge powder-coating system. All the above numerical methods focused on understanding the effect of the electrostatic field on particle motion. In 2001, Bottner and Sommerfeld [7] tried to simulate three-dimensional turbulent coating spray flow under the effect of an electrostatic field using the in-house code FASTEST, which is based on a non-orthogonal, block structured, finite-volume approach. They carried out numerical simulations for two types of powder spray guns and two types of part and suggested that numerical methods can be used to support and optimize the design of powder painting booths. Ye et al. [8] used the commercial computational fluid dynamics (CFD) code, FLUENT, to simulate the electrostatic powder-coating process with a corona spray gun. The simulations were carried out while considering the influence of the gas flow field, electrostatic field and turbulent dispersion on the particle trajectories. The numerical simulation results showed good agreement with the experimental data for the gas velocity profiles and the coating layer thickness deposited on the coated part. These research works showed that numerical modelling and simulation could be used effectively to investigate the effects of various parameters on the powder-coating process [3–8] and optimize the design of the coating booth [7] for required coating performance.

To understand the consequences of switching from the "regular coarse" powder coating of 35 μm and above to a "fine" powder coating of 10–20 μm, numerical simulations were performed in this work to study the complete electrostatic powder-coating process with regular and fine powders. This comprehensive model accounts for the interaction between the gas and particle flow fields. Unlike the other models referred here, this model accounts for the Coulomb force and image force in calculating electrostatic body force, where the electrostatic field solution includes the space charge effect due to the free ions present in the transport region. This numerical model was validated extensively in previous work by Shah [9–11] for its ability to accurately predict the particle trajectories for a given particle size and operating conditions against the experimental data. It was found that the numerical model predicts quite accurately the gas and particle velocities and average particle diameter at different locations inside the coating booth when there was no electrostatic field. Numerical results showed similar effect of electrostatic field on the flow field as that from experimental results. The objective of this paper is to investigate the effect of various operating conditions on the FPTE and coating quality using both coarse and fine powders. Therefore, coating powders of different sizes were used to carry out the numerical simulations and the simulation results were post-processed to obtain the FPTE and coating quality for different size powders. The overall objective of this study was to investigate the performance of fine powders in comparison with coarse powders in an electrostatic powder-coating process.

## 2. Numerical model

The powder-coating system used in this study is shown in Fig. 1, which includes a coating booth, a powder spray gun and a coating part (panel). The powder spray gun inlet is located on the front wall of the coating booth. A $7.6 \times 13.2$ cm-sized coating part was positioned 26 cm downstream of the gun tip with its planar surface perpendicular to the axis of the powder spray gun. The front wall and two sidewalls of the coating booth were open. There is a 3 cm diameter suction hole at the booth top wall, as shown in Fig. 1, which was maintained at a negative pressure (14 kPa gauge) in the booth to keep the powder particles inside the booth.

The 15 cm long corona spray gun shown in Fig. 2 was used in this study to spray the powder. The air-fluidized powder flows through the annular space between the central trumpet-formed, cylindrically shaped, deflector and the outer gun body. The adjustable gun sleeve, which is used to adjust the powder flow pattern, was kept through out this study in the same position as shown in Fig. 2. The