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Inter-particle coating variability in a rotary batch seed coater

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ABSTRACT

Coating of particulate solids by a thin film layer is of interest in many industrial applications such as seed and tablet coating. In seed processing, seeds are commonly coated with a protective coating layer consisting of fertilisers and disease control agents, such as pesticides and fungicides. Batch coaters are commonly used for this purpose. A typical coater consists of a vertical axis cylindrical vessel with a rotating base and a spray disc in the centre, onto which the coating liquid is fed to atomise and spray-coat the seeds. The seeds are driven around the vessel by its rotating base, and are mixed by two baffles; one on either side of the vessel. In the present study, Distinct Element Method (DEM) simulations are used to model the seed coating process. Corn seed are used as a model material and their shape is captured using X-Ray Tomography (XRT), which is approximated in the DEM by clumped spheres. The coating uniformity of the seeds is predicted by implementing a coating model in the DEM, whereby the coating droplets are simulated as very fine spheres projecting tangentially from a ring at the edge of the spinning disk. The size and velocity of droplets leaving the spray disk are measured using high speed video imaging and implemented into DEM simulations. The coating mechanism is represented in the DEM by considering that once a droplet contacts a corn seed, it is removed from the simulation and its mass is attributed to the coating of the corn seed. The distribution of mass of sprayed spheres on the corn seeds and their coefficient of variation are evaluated for a range of process conditions, such as the base rotational speed, atomiser disc position relative to the base and baffle arrangement and designs. It is found that the atomiser disc vertical position, baffle angle and clearance to the wall are most influential, whilst the base rotational speed and baffle width and curvature have only minimal effect.

1. Introduction

Coating of particulate solids by a thin film layer is of interest in many industrial applications, such as seed and tablet coating. Particularly in seed coating, seeds are commonly coated with a protective coating layer consisting of fertilisers and pesticides in order to improve their germination. The quality of the finished product is strongly dependent on the effectiveness of the coating liquid formulation and the level of coverage of the coating on the seeds. The latter is influenced by the motion, mixing and coating phenomena of seeds which are directly controlled by process parameters. Hence,

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understanding the effect of each process parameter on coating uniformity of seeds is essential. To do so, the particle kinematic behaviour (flow field, mixing pattern, etc.) and the residence time of seeds in the coating zone have to be analysed. Discrete Element Method (DEM) (Cundall and Strack, 1979) provides a robust way of simulating particulate systems and has recently been used to address the coating uniformity of pharmaceutical tablet coating (Pasha et al., 2016; Cleary, 2010; Zhu et al., 2008; Hare et al., 2015). Inter- and intra particle coating variability are the two parameters for assessing the coating variability. The former is the variation in the average coating mass from a granule to another, whilst the latter is the distribution of coating liquid on the surfaces of individual granules, in which both factors can be quantified using the coefficient of variation (Kalbag and Wassgren, 2009). Inter particle coating variability is defined as the coefficient of variation of the coating mass amongst the particles.

In the pharmaceutical industry, horizontal axis drum coaters are commonly used for coating tablets with a thin layer of film. In this type of coater, a large number of tablets are placed inside the drum, which is rotated around its axis. The rotational motion of the drum leads to radial and slight axial mixing of the tablets (Muliadi and Sojka, 2010). The coating film is formed by spraying a liquid onto a moving tablet bed. Mixing and uniformity of coating is enhanced by placing a number of baffles inside the drum. This type of coater however is different to those used for coating seeds with two main differences: (i) in seed coating the drum is placed vertically and the motion is brought about by a rotating base; (ii) a rotating disc atomiser is used instead of a nozzle sprayer. However, the two types of mixers share the same underlying particle mechanics and knowledge of the former would help understand the latter for which little has been published in the literature. In contrast, the behaviour of particle beds in rotating drums with horizontal axis has been extensively investigated and reported in the literature (Muliadi and Sojka, 2010; Yamane et al., 1995; Leaver et al., 1985; Park and Wassgren, 2003; Sandadi et al., 2004), where it has been found that the drum filling level and Froude number, $Fr \equiv \omega^2 R/g$ (where ω and R are the rotational speed and radius of the drum and g is the gravitational acceleration) influence the particle flow field.

Suzzi et al. (2012) investigated the effect of tablet shape and fill level on mixing and inter-tablet coating variability in a continuous rotating drum coater for a binary mixture. Considering that mixing promotes good coating, in their study, the mixing efficiency for the all investigated tablet shapes decreased with increasing the fill level of the coater. The dispersive mixing of bi-convex tablets was faster than oval shaped tablets indicating that particle shape should be simulated rigorously. A significantly better performance was achieved at the lowest fill ratio in the case of rounded tablets. In the above work, the inter-tablet coating uniformity was investigated by a first order rate approximation. Moreover, the back-splashing of satellite droplets and the transfer of coating solution from a tablet to neighbouring tablets and walls were neglected. The inter-tablet coating standard deviation was directly correlated to the average fractional residence time of particles in the coating zone, the mass ratio between the droplets retaining and those impinging on the tablet surface, and the rate of droplets arriving on the surface. Based on this approach, Suzzi et al. (2012) concluded that the average fractional residence time of particles in the coating zone decreased with increasing the fill ratio leading to a decline in coating speed.

Kalbag and Wassgren (2009) investigated the inter-tablet coating variability within the spray zone in a horizontal pan coater. They proposed Eq. (1) for estimating the coefficient of variation of the tablet coating at a given time (t),

$$\mathrm{CoV}(t) = \sqrt{\frac{\Delta t_{seg}}{t}\left(\frac{1}{n/N} - 1\right)} \tag{1}$$

where Δt_{seg} is the time that the tablets stay in the spray zone in a quasi-segregated state, n is the number of tablets being coated per coating trial and N is the total number of tablets in the system. They found that the value of Δt_{seg} depended on the geometry of the pan, tablet shape, spraying mechanism and operational conditions. Consequently, a series of experiments or DEM simulations were required to be carried out to determine the value of Δt_{seg}. The authors reported that the coefficient of variation of tablet residence time followed a power law relation with time. Moreover, Δt_{seg} decreased with increasing the Froude number of the pan, aspect ratio of the spray zone, and frictional coefficients of the particles. This led to a more uniform residence time of tablets being present in the spray zone and consequently coating mass on the tablets.

Li et al. (2013) investigated the effect of particle size distribution of spherical particles on coating uniformity in an industrial paddle coater using DEM simulations and spray post-processing analysis, known as ray tracing. The coating mass a particle gains during its kth visit to the spray zone was calculated using

$$\Delta m_{Y,k} = R_y A_{tot} \eta_k t_{S,k} \tag{2}$$

where R_y, A_{tot}, η_k and $t_{S,k}$ are the constant spray flux density, unobscured projected surface area, average exposed area percentage and spray zone residence time during the kth visit to the spray zone. Li et al. (2013) reported that for poly-disperse particles, smaller particles tend to have a relatively high frequency of spray zone visits and low shielding by surrounding particles, leading to higher spray preference toward smaller particles in the system. Just et al. (2013) looked at optimisation of the inter-tablet coating uniformity in a pan coater experimentally, by varying process parameters such as pan load and speed, spray rate, number of spray nozzles and spraying time using a statistical design of experiment approach. A laboratory and a pilot scale pan coaters were used. They reported that a low spray rate and a high pan speed improved the coating uniformity at both scales. The most influential parameter affecting the coating uniformity was found to be the number of nozzles used in the system, where a significant improvement was found by using four spray nozzles as compared to two. They also reported that uniformity of coating was improved by increasing the coating time.

In conclusion, the DEM simulations have proved useful in developing a better understanding of coating operation and optimising it. The methodologies developed for predicting the variation of coating can be extended and applied to corn seed coating. However, no such analysis of coating optimisation has so far been reported for seed coaters in the literature. Hence, in this study the effect of seed coating process parameters on coating uniformity of corn seeds is addressed.