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Use of swirling airflow to enhance coating performance of bottom spray fluid bed coaters

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Abstract

As there is strong interest in coating increasingly smaller particles or pellets for use in compacted dosage forms, there is a need for better small particle coating systems. This study explored the use of swirling airflow to enhance the performance of the bottom spray coating system. Firstly, pellet coating in the non-swirling airflow of conventional Wurster coating was compared with that of swirling airflow in precision coating under standardized conditions. Secondly, precision coating was studied in greater details at different airflow rates (60–100 m^3/h) and partition gaps (6–22 mm). Precision coating was found to have higher Reynolds numbers (*Re*) than Wurster coating, indicating higher turbulence. It produced coated pellets of better properties than Wurster coating, having less agglomeration and gross surface defects, more uniform coats, increased flow and tapped density, and slower drug release. Higher surface roughness did not affect the yield. In precision coating, increasing airflow rates decreased the degree of agglomeration but had minimal effect on pellet quality attributes (colour intensity, colour uniformity and surface roughness) and yields. Increasing partition gaps increased the degree of agglomeration proportionally, but this effect was small. However, greater changes in yield, surface roughness, colour intensity and colour uniformity were detected. This study showed that precision coating, while having a higher drying ability, was able to maintain the same yield and produce coated pellets with superior quality compared to Wurster coating. In precision coating, airflow rate had greater influence on the drying of pellets while partition gap had greater influence on pellet quality attributes.

Keywords: Coating; Swirl; Pellets; Airflow; Partition gap

1. Introduction

Coating of multiparticulates plays an important role in the pharmaceutical industry (Collett and Moreton, 2001; Hogan, 2001). By applying different coating materials onto multiparticulates, various desirable functional properties such as resistance to acid (Huyghebaert et al., 2005), sustained release (Chang and Robinson, 1990) and targeted release (Gupta et al., 2001) may be obtained. Fluid-bed coating is a popular method of coating multiparticulates due to its high throughput and formation of good quality coats. It is carried out using the air-suspension method in which air is passed through a perforated (air distribution) plate, suspending the substrate in air and drying the coats that are sprayed onto the substrate particles from the nozzle (Deasy, 1984).

Fluid-bed coating of particles of millimeter size range is well established and poses little problems due to their larger sizes. However, with increasing interest in the coating of smaller and smaller particles even down to micron sizes (Bechgaard and Nielsen, 1978), the propensity of small particles to aggregate or agglomerate during coating becomes a major rate-limiting factor in attempts to coat particles (Jono et al., 2000). Hence, many studies have been conducted to investigate factors such as coating material (Tatsu and Hiroshi, 2001; Wong et al., 2002), core particles (Saleh et al., 2003), equipments properties (Yang et al., 1992) and coating process parameters (Hiroyuki et al., 2003) that might affect the degree of agglomeration during coating.

The interest of this study was to investigate the influence of airflow pattern on the performance of coating, in particular its effect on agglomeration of particles during coating. Swirling airflow has been widely studied in theory and in the engineering field but its knowledge in the pharmaceutical coating field is limited. Hence, the effect of swirling airflow in precision coating

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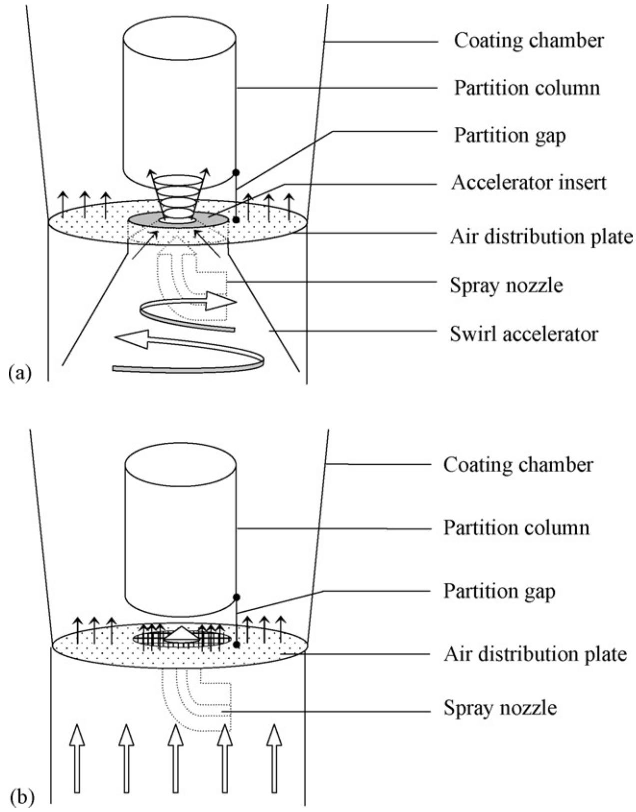

Fig. 1. Diagrams of the air distribution plates and associated parts of the (a) precision coater (PC) and (b) aerocoater (AC), with arrows showing the airflow pattern.

(Walter, 1998) was compared to non-swirling airflow in Wurster coating (Fig. 1) under similar conditions.

Swirling airflow is airflow with a rotational motion about the central axis. The degree of swirl is dependent on the amount of tangential motion corresponding to the amount of axial motion (Ozbey and Soylemez, 2005). Many studies had concluded that swirling airflow was able to improve heat transfer rates (Ozbey and Soylemez, 2005; Yilmaz et al., 1999, 2003; Algifri et al., 1988; Kevat et al., 2005) and mixing of components (Ozbey and Soylemez, 2005) as compared to non-swirling airflow. This could be attributed to the increased flow paths in swirling airflow which increased the energy dissipated by friction and caused angular acceleration to the flow (Yilmaz et al., 2003), and also to the increased pressure drop near the central rotation axis of swirling airflow which increased the velocity of flow and presumably reduced the boundary layer thickness (Yilmaz et al., 1999; Shtern et al., 1998). These effects would be beneficial in bottom spray coating for the spreading of deposited coating droplets and drying of the coatings, hence increasing the coating efficiency and improving coat quality attributes.

The above paragraph suggests that the nature of the airflow in coaters is important in affecting their performances. It was hypothesized that a system with higher turbulence would have better performance in coating. Hence, the Reynolds number (*Re*) of each airflow pattern was determined to assess the type of airflow in the coaters, at which a low *Re* describes lamellar flow which is slow and smooth, while a high *Re* describes turbulent flow which is fast and chaotic (Mott, 1994). *Re* is an important non-dimensional number in fluid dynamics that provides the criterion for comparing geometrically similar bodies (McKenzie, 1997). *Re* is the ratio of inertial forces to viscous forces, whereby the inertial forces are derived from Newton's second law of motion ($F = \text{ma}$) and viscous forces derived from the product of shear stress and area (Mott, 1994). For systems with high *Re* values, viscous forces would have less impact on fluid flow. This would be beneficial in fluid-bed coating as "viscous forces" of the fluidizing particles build up due to the wetting of particles during coating, and may cause sluggish flow that impede the coating process.

In view of the importance of airflow pattern on the eventual product quality and the lack of evidence of the swirling air effects on pharmaceutical particle coating, the effects of swirling airflow on performance of coating of pharmaceutical products were investigated, in particularly, reducing the agglomeration of particles being coated.

2. Materials and methods

2.1. Materials

Sugar pellets (Neutral pellets, Hanns G. Werner GmbH + Co., Germany) of size ranging from 500 to 600 μm were used as substrates for this study. Coating materials consisted of hypromellose (HPMC: Methocel E3: Premium LV EP, DOW Chemical, USA), polyvinyl pyrollidone (PVP: Plasdone C-15, ISP Technologies, USA), red pigment (Sicopharm Red 30, BASF Corporation, Germany), chlorpheniramine maleate (CM: Merck, USA) and ethyl cellulose coating dispersion (Surelease, Colorcon, USA). Deionised water was used as the solvent for all the coating materials.

2.2. Methods

2.2.1. Coating of pellets

Precision coating and Wurster coating were carried out using the Precision Coater (PC: GEA Aeromatic-Fielder, UK) and Aerocoater (AC: GEA Aeromatic-Fielder, UK), respectively. These were fitted using the same air handling system (MP-1 Multi-processor, GEA Aeromatic-Fielder, UK), partition column (8 cm diameter and 25 cm height) and conical acrylic coating chamber. Each coater was equipped with a two-fluid spray nozzle which had similar nozzle tip diameter (1 mm), air cap opening diameter (2.5 mm) and nozzle tip protrusion (1 mm from the flushed position). The air distribution plate for Wurster coating consisted of a 2% open area Fiedler plate with bi-cylindrical holes such that the diameter on the airside was 1.6 mm and product side was 0.71 mm. The precision coating system required fitting an accelerator insert with air inlet diameter of 20 mm.

For the comparative study of Wurster coating and precision coating, coating was carried out under conditions listed in Table 1. Pellets used for agglomerative or colour coating were base-coated. Base coating was carried out using a high atomizing pressure of 2 bars to minimize the formation of agglomerates.

Table 1
Conditions used for various coating methods in the comparison of AC and PC

Process parameters	Coating methods				
	Base coating	Agglomerative coating	Colour coating	Base coating with drug	Ethyl cellulose coating
Coater	AC	AC and PC	AC and PC	PC	AC and PC
Coating formula	HPMC 5%, PVP 1%	HPMC 5%, PVP 1%	HPMC 5%, PVP 1%, red pigment 0.67%	HPMC 5%, PVP 1%, CM 2%	Surelease 15%
Batch size (kg)	3	1	1	3	1
Airflow rate (m^3/h)	100	80	80	100	100
Atomizing pressure (bar)	2	1.5	1.5	2	2
Inlet air temperature (°C)	70	70	70	70	65
Partition gap (mm)	18	14, 18, 22	18	18	18
Spray rate (g/min)	14	14	10	14	14
Coating level (% w/w)	2	6	2	8	2

Conditions for agglomerative coating were chosen to deliberately encourage agglomeration, and colour coating was done at a lower spray rate to avoid agglomeration. As partition gap may affect the outcome of coating, agglomerative coating was carried out over a range of partition gaps (14, 18 and 22 mm) in both coaters. Other pellets were base-coated with drug followed by ethyl cellulose coat. After coating, all the pellets were dried in the oven at 60 °C (with the exception of ethyl cellulose-coated pellets at 35 °C) for 12 h before undergoing further tests.

For the study of precision coating, sugar pellets were based-coated prior to agglomerative coating and colour coating (Table 1). The latter two coating methods were carried out at airflow rates of 60, 70, 80, 90 and 100 m^3/h and partition gaps of 6, 10, 14, 18 and 22 mm. When airflow rates were studied, partition gap of 18 mm was used. When partition gap was studied, airflow rate of 80 m^3/h was used.

2.2.2. High speed photography

Sugar pellets were circulated under similar conditions of airflow rate (60 m^3/h) and partition gap (18 mm) in both coaters without spraying of coating material. A transparent acrylic partition column was used to allow the pellets to be seen within the partition column. Photographs were taken using a high speed camera (Motionpro HS-4, Redlake, AZ) at 2770 frames per second. Using slow speed playback, 30 randomly chosen pellets were individually tracked to determine the pellet velocities.

2.2.3. Derivation of Re

The Reynolds number, Re, was determined from Eq. (1), whereby ρ is fluid density, v_s is fluid velocity, L is pipe diameter, and μ is dynamic fluid viscosity (Mott, 1994; McKenzie, 1997):

$$Re = \frac{\rho v_s L}{\mu} \quad (1)$$

The Re of airflow within the partition column was determined as it was the location where the coating took place and would be important in affecting the performance of coating. In the calculations, the density (1.225 kg/m^3) and dynamic fluid viscosity (0.0179×10^{-3} Pa s) of air at atmospheric pressure and temperature were used. The pipe diameter was the diameter of the partition column (8 cm). Due to technical difficulties of measuring the air velocity within the partition column, pellet velocities were used as an approximation of the air velocities within the partition column.

2.2.4. Characterization of uncoated and coated pellets

In the comparative study of Wurster coating and precision coating, pellets were coated using agglomerative coatings and the resultant products were analyzed for yield, degree of agglomeration, flow and packing properties, surface roughness and surface morphology. Colour coated pellets were analyzed for colour and colour uniformity, and drug coated ethyl cellulose pellets were analyzed for drug release profile.

In the study of precision coating, pellets coated by agglomerative coating were analyzed for yield, degree of agglomeration, surface roughness. Colour coated pellets were analyzed for colour and colour uniformity.

The yield (Yd) was determined as the final weight of coated pellets (W_F) as a percentage of the theoretical final weight of coated pellets (W_T). The theoretical final weight of the pellets was the sum of the weight of load and the solid content in the coating material applied:

$$\mathrm{Yd}\,(\%) = \frac{W_F}{W_T} \times 100 \quad (2)$$

After measuring the yield, the degree of agglomeration (Agg) was determined by sieving all the coated pellets through a 710 μm pore size sieve. The pellets retained by the sieve were weighed (W_A) and the degree of agglomeration calculated as follows:

$$\mathrm{Agg}\,(\%) = \frac{W_A}{W_F} \times 100 \quad (3)$$

Unagglomerated pellets were used for the next four tests. Whole surfaces of the pellets were observed using a scanning electron microscope (JSM-5200, Jeol, Japan) after pretreatment of samples by gold sputtering.

Angle of repose (α_r) of pellets was determined using a powder tester (PT-N, Hosokawa, Japan). Pellets were fed through a funnel onto a fixed base, forming a cone. The α_r was determined using an angle pointer by positioning it parallel to the cone surface. Five measurements were obtained for each sample.

Pellet bulk density (ρ_b), tapped density (ρ_t) and Hausner ratio were determined using a USP Tap Density Tester (TD2, Sotax, US). Pellets were filled up to 100 ml in a graduated cylinder and the weight of the pellets (w) was determined. The pellets were then subjected to tapping until a constant volume (v_c) was attained. Three measurements were obtained for each sample. ρ_b, ρ_t and Hausner ratio were defined as follows:

$$\rho_b = \frac{w}{100} \quad (4)$$

$$\rho_t = \frac{w}{v_c} \quad (5)$$

$$\text{Hausner ratio} = \rho_t/\rho_b \quad (6)$$

Pellet surface roughness was determined using a scanning probe microscope (SPM-9500J, Shimadzu, Japan) with an E tube scanner of $100(x) \times 100(y) \times 10(z)$ μm in scan range. The probe was scanned over an area of 25 μm × 25 μm using the dynamic mode and a Z range of 10 μm. Eight pellets were randomly selected from each batch for analysis. The degree of surface roughness was expressed by arithmetic mean roughness, Ra, where a higher value indicated greater surface roughness.

For colour coated pellets, the tristimulus colorimeter (Chroma Meter CR-241, Minolta, Japan) was used to determine the colour over a 0.3 mm diameter circular spot on the surface of each pellet. The light source, standard illuminant D65, consisted of average daylight including ultraviolet wavelength region. Colour measurements were taken and expressed in *Lab* colour space as was previously described (Chan et al., 2001). Measurements were taken for 30 randomly chosen pellets for each batch. The colour difference, dE, of each spot with respect to the initial colour of the pellets before colour coating was defined by the following equation:

$$\text{dE} = [(L_C - L_W)^2 + (a_C - a_W)^2 + (b_C - b_W)^2]^{1/2} \quad (7)$$

where the subscript "C" refers to the coloured sample and "W" refers to the white base-coated pellets. The colour uniformity between pellets was indicated by the relative standard deviation (R.S.D.) of dE, in which the lower the value, the greater the colour uniformity. dE and R.S.D. of dE of coloured pellets for each batch were represented by their average values obtained over 0.4, 0.8, 1.2, 1.6 and 2% coating level.

Drug release profiles of pellets coated with drug (chlorpheniramine maleate) and ethyl cellulose coats were obtained from dissolution studies which were carried out in 900 ml of deaerated distilled water maintained at 37 ± 1 °C, using a paddle method (Method II, USP XXII; 72-RL, Hanson Research, USA) at a stirring speed of 100 rpm. The weight of the pellets used was 5 g, containing approximately 100 mg of drug. At preselected intervals, 4 ml samples were collected using an automated sampler (Dissoette 27-6A, Hanson Research, USA). Liquid removed by sampling was not replaced and this loss in volume of the dissolution medium was taken into consideration during calculation. The amount of drug was determined spectrophotometrically at 262 nm and calculated from the Beer's plot of the

(a)

(b)

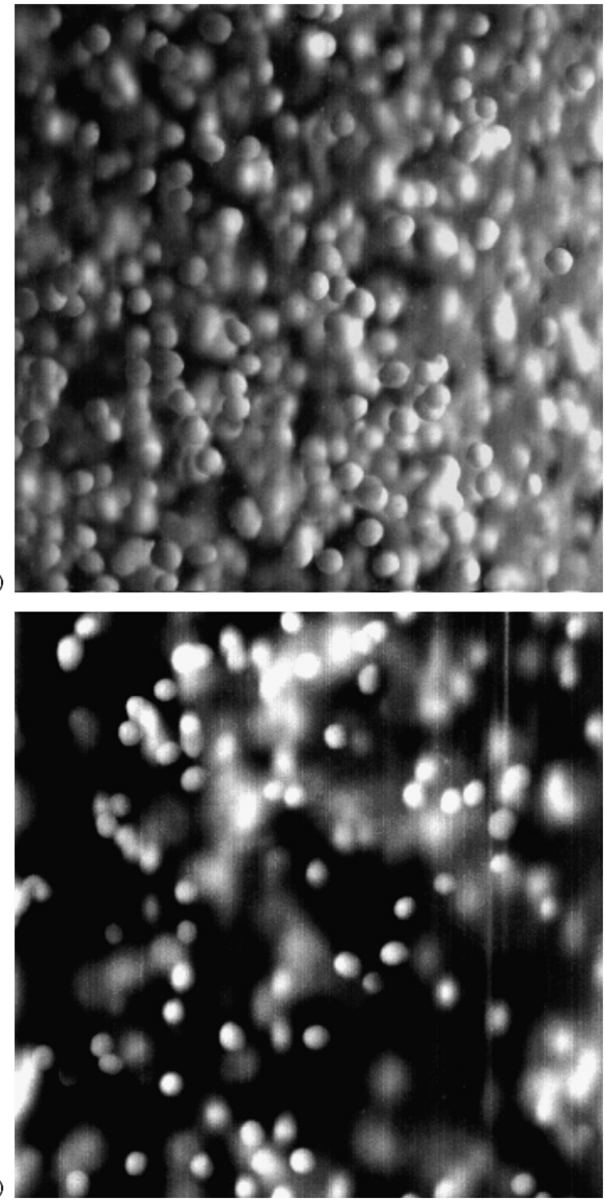

Fig. 2. High speed photographs of pellets within the partition column in (a) Wurster coating and (b) precision coating over an area of 2 cm × 2 cm.

Table 2
Summary of results obtained in the comparison of AC and PC

Parameter	AC	PC
Pellet velocity (m/s)*	1.5 ± 0.2	5.3 ± 1.1
*Re**	8204 ± 1031	29160 ± 6141
Degree of agglomeration (%)*	17.27 ± 11.82	0.93 ± 0.44
Yield (%)	99.28 ± 0.18	99.11 ± 0.15
Angle of repose (°)*	34.3 ± 0.6	33.7 ± 0.5
Hausner ratio*	1.042 ± 0.013	1.030 ± 0.015
Surface roughness, Ra (nm)*	221.2 ± 73.3	304.9 ± 90.1
Colour, dE	31.2 ± 1.0	31.4 ± 0.3
R.S.D. of dE (%)*	24.9 ± 1.33	14.2 ± 0.45

* Two sample t-test showed significant difference in means ($p < 0.05$).

standard drug solutions. Triplicates were carried out for each sample.

2.2.5. Statistics

Independent-sample *t*-test was used to compare 2 sample sets for equality. One-way ANOVA was used to compare more than 2 sample sets with Tukey's test as the post hoc analysis. Sample means were significantly different if $p < 0.05$.

3. Results and discussion

3.1. Comparison of Wurster coating and precision coating

High speed photographs of pellets moving within the partition column showed that the pellets in precision coating were less packed and moved at a more disorderly fashion than in Wurster coating (Fig. 2). The average speed of pellets moving up the

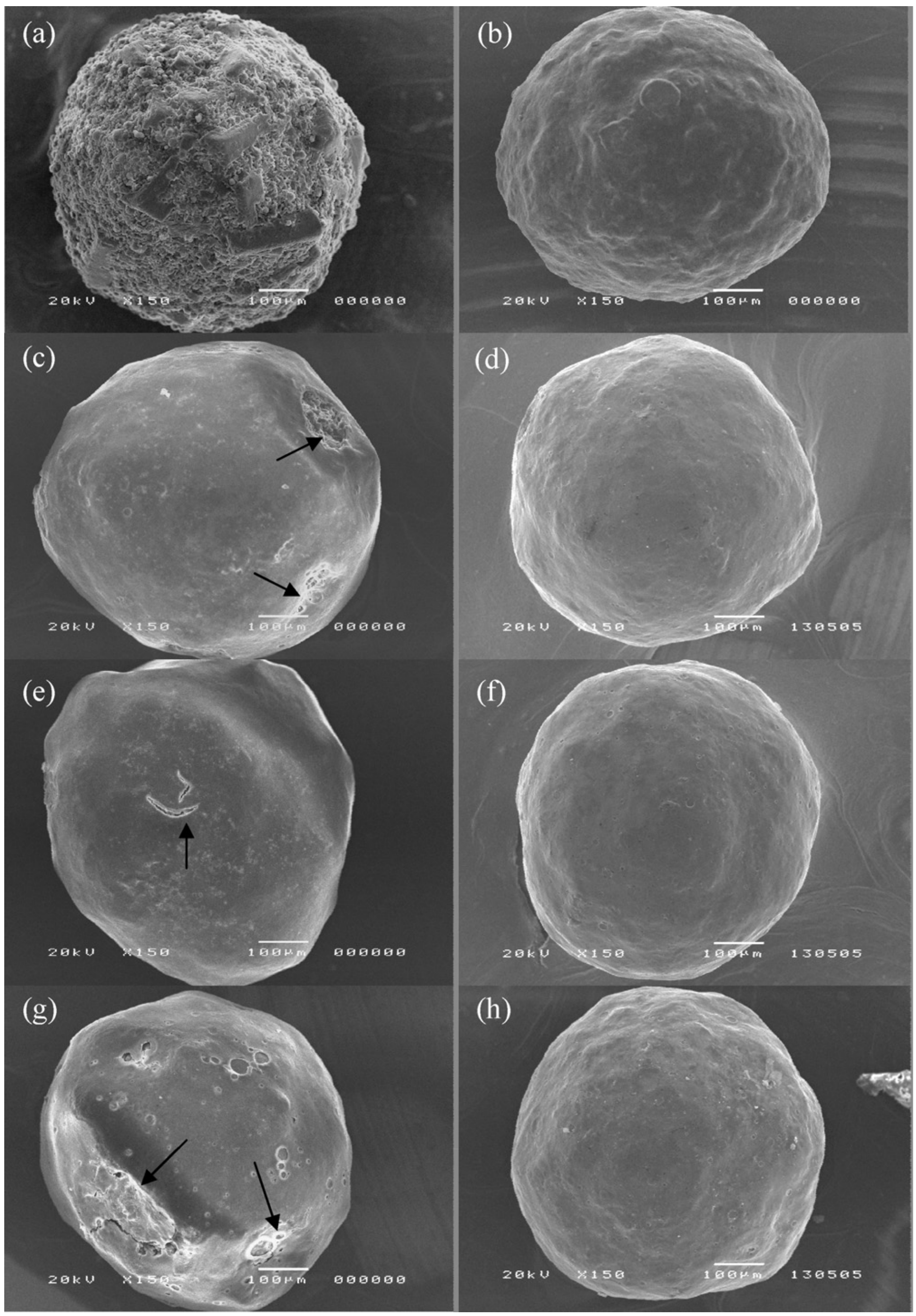

Fig. 3. Scanning electron micrographs of (a) uncoated pellet, (b) base-coated pellet, (c) pellet coated by Wurster coating at partition gap of 14 mm, (d) pellet coated by precision coating at partition gap of 14 mm, (e) pellet coated by Wurster coating at partition gap of 18 mm, (f) pellet coated by precision coating at partition gap of 18 mm, (g) pellet coated by Wurster coating at partition gap of 22 mm, and (h) pellet coated by precision coating at partition gap of 22 mm.

partition column in precision coating was about 3.5 times faster than in Wurster coating (Table 2). *Re* values showed turbulent flow within the partition column in both Wurster and precision coating, being more dominant in precision coating, indicating that there was indeed higher turbulence in the swirling airflow (Table 2).

A large difference in degree of agglomeration was observed between precision coating ($0.93 \pm 0.44\%$) and Wurster coating ($17.3 \pm 11.8\%$). The lower degree of agglomeration in precision coating indicated that there was better pellet drying and separation during the coating process. Viscous forces between pellets built up during coating when pellets were wetted by the spray material and caused pellet flow to deteriorate and become sluggish. The higher *Re* value in precision coating indicated that the flow of pellets was less influenced by viscous forces. This could be attributed to the swirling airflow which swirled and accelerated the pellets during their passage through the spray zone providing shear force to break any liquid bridges that may be present between adhering pellets, thus preventing agglomeration from occurring. The swirling airflow also increased the speed at which pellets passed through the spray zone preventing excessive wetting, and caused pellets to reach a greater height in the coating chamber increasing their exposure to the drying air in the chamber.

From visual observation and high speed images (Fig. 2) of pellet movement during coating, there was clearly scarcer pellet flow through the partition column in precision coating than in Wurster coating, showing that there was better pellet separation in the spray zone. This was also reported by Chan et al. (2006), whereby the pellet mass flow rate in Wurster coating was found to be higher than precision coating. This could be attributed to the accelerator insert used in precision coating which was not perforated but had a central opening. This design caused a high velocity airflow in the centre, which sucked in pellets and sent them strongly up the partition column, rather than being dependent on gravitational flow aided by the fluidizing peripheral air and blown up the partition column as in Wurster coating (Fig. 1) (Chan et al., 2006). The latter resulted in denser pellet distribution in the coating zone which encouraged agglomeration (Fig. 2).

From the scanning electron micrographs of pellets (Fig. 3), it could be observed that the pellets were coated differently. The coats obtained using Wurster coating (Fig. 3c, e and g) showed many gross defects as highlighted in the micrographs, whereas precision coating gave relatively good coats with much less observable gross defects (Fig. 3d, f and h). These gross defects were probably picking of the coats which occurred due to transient coalescence or sticking by liquid bridges between pellets that later broke off. This was a sign of over-wetting in the Wurster coating despite the use of identical coating conditions. Not considering defects in the Wurster coated pellets, uncoated pellets were observed to be the roughest, followed by pellets coated by precision coating and lastly, pellets coated by Wurster coating. This was substantiated by Ra values obtained by SPM, which showed that uncoated pellets had the highest mean Ra value of 540 nm, and that the surfaces of coats obtained by precision coating were significantly rougher than those by Wurster coating (Table 2). The rougher surface in precision coating was probably due to the better contoured ellipsoidal footprints of the spray droplets which appeared as clearly demarcated and overlapping mosaic-like leaves (Fig. 4b). In contrast, the footprints of droplets formed by Wurster coating appeared to have merged together and beaten-down, creating a smoother surface (Fig. 4a). The conditions of slower drying and more frequent collisions had contributed to less rough films. The observation in precision coating was probably indicative that deposited spray droplets dried more rapidly after they were coated. The appearance of dried deposited spray droplets as clear well-demarcated footprints also provided evidence that the pellets were well separated from each other as they passed through the spray zone and transit the partition column. There were fewer impacts on the droplets' footprints to aid in flattening them as they were being dried.

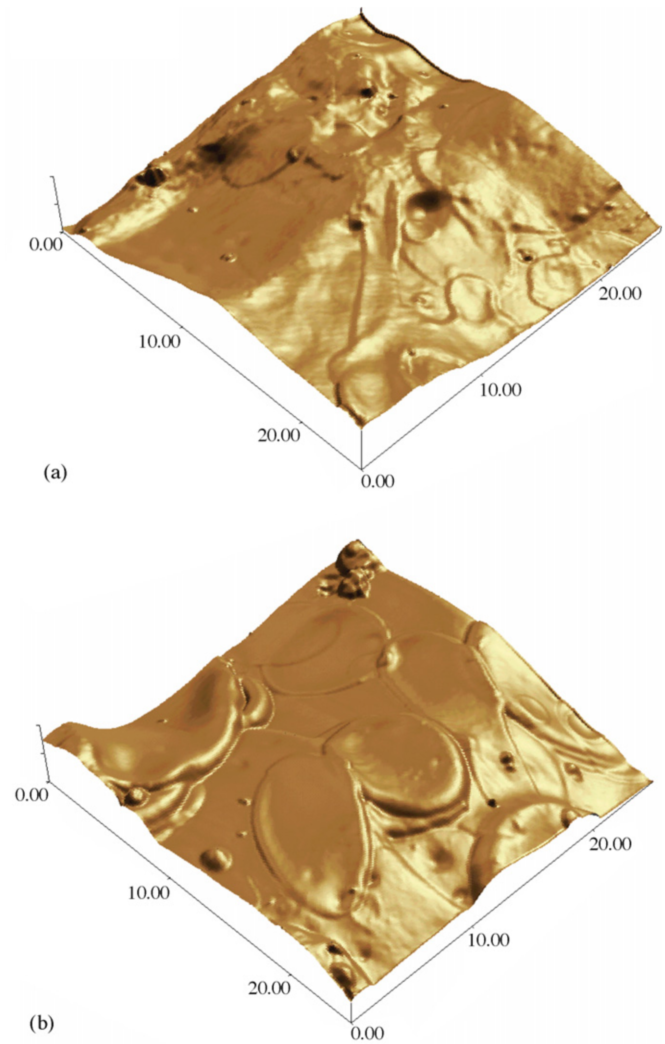

Fig. 4. Scanning probe micrographs of the surface of a pellet coated by (a) Wurster coating and (b) precision coating over an area of 25 μm × 25 μm.

While roughness of pellets contributed by gross defects was not reflected in the determined Ra value as the very rough pitted areas of the coated pellets were deliberately avoided during roughness measurements, overall pellet surface roughness was evident in the flow and packing studies. Angle of repose and Hausner ratio showed that coated pellets obtained by precision coating flowed better and had better packing properties than those obtained by Wurster coating (Table 2). Gross defects observed in Fig. 3c, e and g were the most likely explanation for this observation as they caused higher friction between the pellets during flowing and packing.

Despite the higher turbulence in precision coating as discussed earlier, there were no significant differences observed between the yields obtained in both coating processes (Table 2). The yield was a measure of the amount of coating material deposited onto the pellets. This indicated that loss of coating material by spray-drying effect or attrition was similar in both coating processes, showing that the increased turbulence was not detrimental to the pellets coated. The colour differences, dE, were also similar (Table 2), substantiating the above results that the amount of coating material deposited were comparable. However, the R.S.D. of dE, which described the coating uniformity, was found to be significantly lower, i.e. better in precision coating (Table 2).

The more uniform coating observed in precision coating showed that there was enhanced pellet movement. This could again be attributed to the higher turbulence generated by the swirl accelerated airflow. The swirling action increased the flow path of pellets and the exposure of their faces to the spray material, forming a more uniform coating. The swirling air may also contribute to spinning of the pellets as they flow through the coating zone. However, in the non-swirling flow of pellets in Wurster coating, the pellets would have taken a straight path through the spray zone resulting in unidirectional exposure of the pellet surface to the spray zone, with more depositing on the surface facing the direction of the spray material, resulting in uneven one-pass distribution of spray material on the pellet surface. The difference in coat uniformities could also be explained by differences in pellet movement in the product/storage bed during coating. In precision coating, the pellets in the storage bed were observed to be less fluidized and descended gradually before being transported up the partition column, whereas in Wurster coating, pellets appeared to be in constant low amplitude flux caused by the peripheral fluidizing air at the storage bed before being moved into and transported up the partition column. This showed that a non-turbulent queue system was probably present in the storage bed in precision coating but not in Wurster coating.

A drug release study was carried out to determine if such differences in uniformity of coat could contribute to changes in drug release profiles. Chlorpheniramine maleate was incorporated because of its high solubility in water and hence, its release would be solely dependent on the sustained release function of the ethyl cellulose coat applied and not be affected by its solubility. From Fig. 5, it could be concluded that the higher uniformity of coats formed by precision coating caused the drug to be released at a lower rate than those coated using Wurster coating. The medium with pellets coated by Wurster coating turned turbid at the end of the run, indicating that the sugar pellet cores had disintegrated. The medium which held pellets coated by precision coating appeared much clearer with pellets still intact.

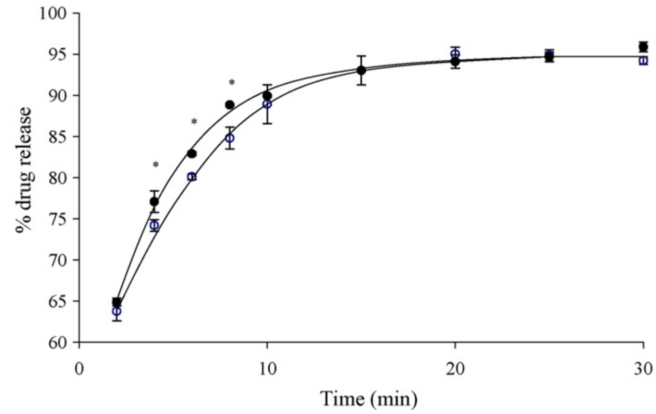

Fig. 5. Drug release profile of drug loaded pellets coated by Wurster coating (●) and precision coating (○). *Significant difference in means ($p < 0.05$).

This was indicative of the superior encapsulation efficiency of ethyl cellulose coat deposited by precision coating, an indication that the coating was possibly better formed, more uniform and less damaged.

These results showed that the higher turbulence generated by the swirling airflow in precision coating enabled better performance in coating, especially from the reduction in agglomeration and increase in coat uniformity. Hence, this makes *Re* value a good predictor of coating performance. Even with swirling airflow incorporated into the conventional pellet coating system, there will be improvements in coat quality and this would be associated with less likelihood of failures, better reproducibility, reduced coating materials requirement and coating times.

3.2. Characteristics of precision coating

Airflow rate and partition gap were identified as major variables that could affect the performance of precision coating, hence they were further investigated. Performance indicators used included degree of agglomeration, yield, surface roughness, colour intensity and colour uniformity.

The inlet airflow served to provide both the circulation of pellets and drying needs of the coater. However, excessively high airflow rates were undesirable due to spray-drying effects on the coating media and attrition of substrates undergoing coating. With an increase in airflow rate, the yield increased significantly from 99.0 to 99.4%, then decreased linearly to 99.0% (Fig. 6). At the lowest airflow rate of 60 m^3/h, the freshly coated pellet were probably not dried completely, depositing some coat material onto the wall of the coater as they came into contact with it. At the airflow rate of 70 m^3/h, the yield was at a maximum (99.4%), showing that spray-drying effects were probably at the lowest. With increasing airflow rates, the yield decreased in a linear pattern ($R^2 = 0.99$) indicating that the amount of spray drying and likely attrition increased proportionally with the increase in airflow rate.

The degree of agglomeration decreased considerable from 7.85 to 2.50% when the airflow rate was increased from 60 to 70 m^3/h, and approached a plateau at higher airflow rates

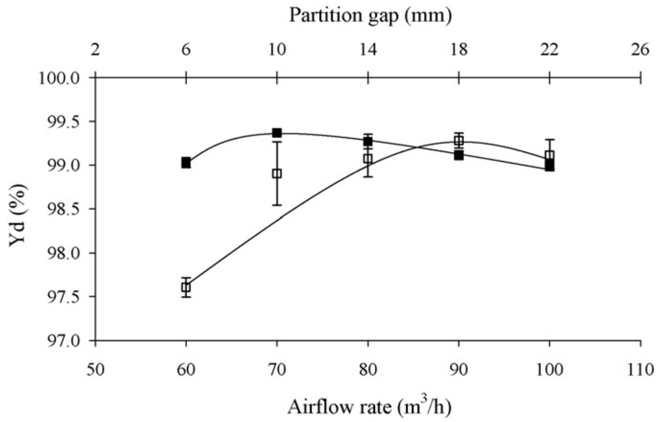

Fig. 6. Yield as a function of airflow rate (■) and partition gap (□) in precision coating.

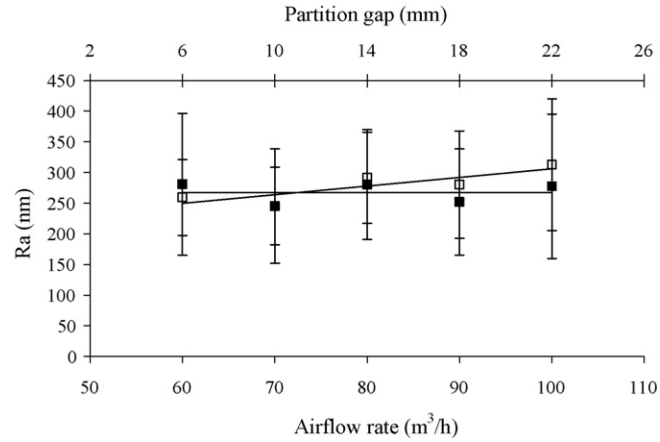

Fig. 8. Surface roughness as a function of airflow rate (■) and partition gap (□) in precision coating.

(Fig. 7). The sudden decrease in agglomeration was an indication that sufficient drying capacity provided by the inlet air was reached. The above discussion on effect of airflow rate on yield also suggested that the drying capacity was reached at around 70 m^3/h. Slight reductions in degree of agglomeration beyond this airflow rate were probably due to increased attritive environment which rapidly broke down any freshly coalesced particle–particle agglomerates.

Airflow rate had minimal effect on pellet quality over the range studied. It did not affect the surface roughness (Fig. 8), colour intensity (Fig. 9) and colour uniformity (Fig. 10) of the coated pellets significantly. This indicated that the swirling airflow pattern in precision coating continued to provide a conducive coating environment even when increasing the airflow rate beyond its optimal value.

The partition gap controls the flow of pellets into the partition column (Fitzpatrick et al., 2003). When the partition gap was smallest (6 mm), the yield was the lowest (97.6%) (Fig. 6). The narrow partition gap probably restricted the pellet mass flow into the partition column, resulting in scarce distribution of particles within the coating zone. This resulted in deposition failures of spray droplets and thus loss of coating material to the surrounding partition column wall and by spray drying. Increasing

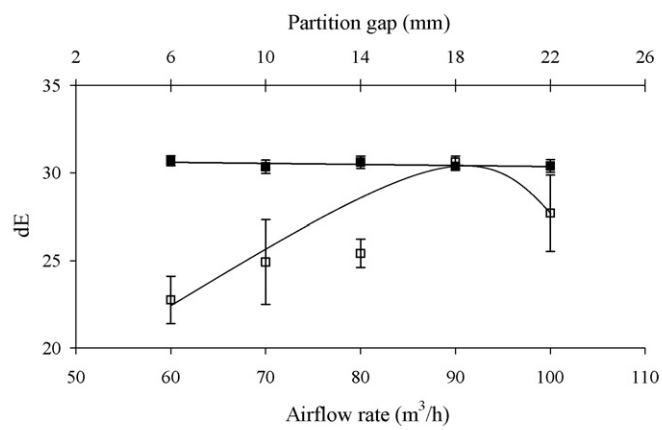

Fig. 9. Colour intensity as a function of airflow rate (■) and partition gap (□) in precision coating.

the partition gap increased the final product yield, reaching a peak (99.1%) at the partition gap of 18 mm. The same trend was observed in the colour of pellets, with a clear maximum (dE of 30.6) at the partition gap of 18 mm (Fig. 9). The slight decrease in yield and colour intensity at the larger partition gap

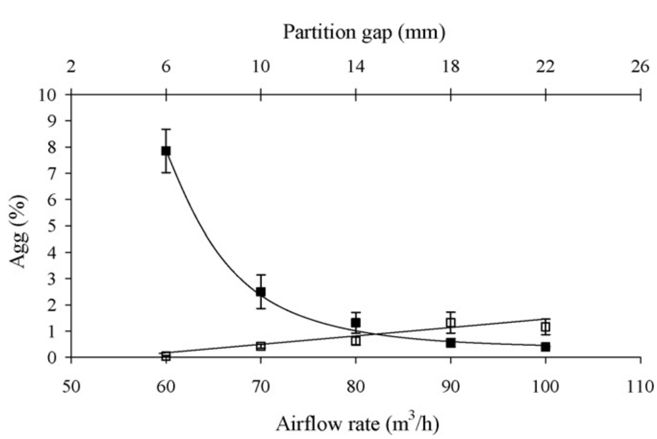

Fig. 7. Degree of agglomeration as a function of airflow rate (■) and partition gap (□) in precision coating.

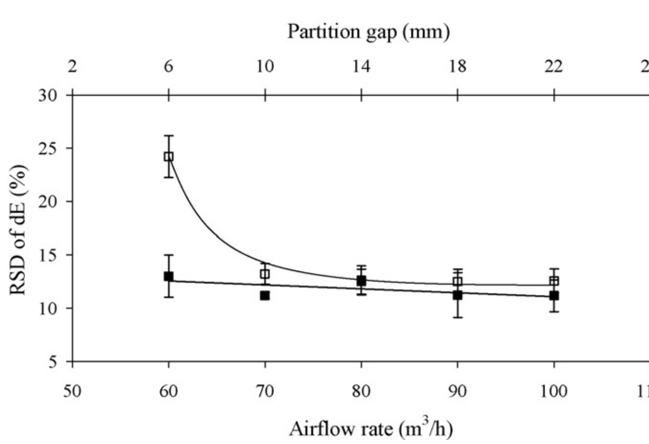

Fig. 10. Colour variation as a function of airflow rate (■) and partition gap (□) in precision coating.

of 22 mm was probably because of the lower transit velocity of pellet flow into and across the partition gap causing marginally increased localized over-wetting and greater likelihood of coalescence between wetted surfaces conveying slower through the partition column wall.

Colour uniformity was lowest at the partition gap of 6 mm (R.S.D. of dE = 24.2%) and increased (R.S.D. of dE = 13.2–12.5%) with increase in partition gaps, leveling off beyond a gap of 14 mm (Fig. 10). The narrow partition gap of 6 mm restricted the pellet mass flow from the storage bed into the partition column and this could have resulted in longer resident time in the storage bed as well as reduced cycling rate through the spray zone. The reduced cycling rate did not favour coating uniformity. Beyond the effects of more restricted mass pellet flow through the gap, pellets entering probably transited through the spray zone faster, enough to maintain a more unidirectional flow and hence, likelihood for a wider circumferential coating in one pass would be diminished. Thus, the combination of reduced cycling rate and less favourable coat distribution conditions produced an overall poorer coat quality for pellets coated using a partition gap of 6 mm.

There was strong correlation ($R^2 = 0.95$) between the degree of agglomeration and partition gap (Fig. 7). When the partition gap is increased, the movement of pellet feed into the spray zone would be proportionally increased. For a fixed airflow rate, the velocity of pellet movement through the partition column would be expected to decrease proportionally, leading to more sluggish movement of particles in the partition column (Deasy, 1984). This could have resulted in conditions for increased tendency of agglomeration especially with bigger partition gaps. However, this effect was still very small as the change in the degree of agglomeration only increased by about 1%. There was a slight increase in surface roughness (Fig. 8) with partition gap, which could be due to increased formation and breakage of liquid bridges. However, this was not found to be significant.

These results indicated that partition gap had relatively minimal influence on the drying of pellets but had some effects on pellet quality. This showed that amount of particles the swirling airflow influenced the manner at which particles get coated in the spray zone. Nevertheless, despite the large changes in partition gap and airflow rate used, there were little or no significant changes in the various performance parameters studied. This demonstrated the robustness of precision coating in which swirling airflow was employed.

A closer look at the precision coating system gave a better understanding of how the swirling airflow affected its performance in coating. The flow rate of the swirling air was found to affect the drying of the particles whereas it was the feeding of particles into the swirling airflow which affected the quality of the products formed. Increasing airflow rates reduced agglomeration by increasing the drying capacity and pellet transit velocity but this had no significant effect on the coat qualities such as colour intensity, colour uniformity and surface roughness. There was an optimal airflow rate at which the yield was maximal, beyond which some spray drying occurred and caused a decrease in yield. This showed that airflow rate had more impact on the drying of pellets than on pellet quality. The partition gap, on the other hand, seemed to have greater influence on pellet quality. An optimal partition gap was found to be necessary to bring about the best yield, colour intensity and uniformity of coating of pellets. The degree of agglomeration and surface roughness increased with partition gap but these effects were small. These findings indicated that the partition gap, which controlled the amount and velocity of pellets passing through the partition column, affected the pellet coating process.

4. Conclusion

From this study, the influence of swirl accelerated airflow in precision coating evidently improved the performance of bottom spray fluid-bed coating. Comparison of the two types of airflow pattern showed that the swirling airflow of precision coating had enabled more uniform coating with less agglomeration and gross defects. As such, flow, packing and sustained release profile of the coated pellets were enhanced. This was attributed to the increased turbulence of the swirling airflow as shown by the *Re*. Hence, it is a better choice especially for the coating of small particles.

With the knowledge of the influence of airflow pattern and process parameters (airflow rate and partition gap) on the coating performance factors, the coating process in precision coating and Wurster coating were better understood. It is anticipated that this understanding of swirling airflow in bottom spray fluid-bed coating would aid in successfully coating of fine particles by utilizing optimized coating conditions and further coater engineering refinements. Even for normal pellet coatings, improved efficiencies enabled higher coating throughput as well as better quality end products.

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