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Comparative Study of the Fluid Dynamics of Bottom Spray Fluid Bed Coaters

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ABSTRACT

Fluid dynamics of pellets processed in bottom spray traditional Wurster coating and swirl accelerated air (precision) coating were compared with the intent to understand and facilitate improvements in the coating processes. Fluid dynamics was described by pellet mass flow rate (MFR) obtained using a pellet collection system and images captured using high speed photography. Pellet flow within the partition column was found to be denser and slower in Wurster coating than in precision coating, suggesting a higher tendency of agglomeration during the coating process. The influence of partition gap and load on the MFR indicated that the mechanism of transport of pellets into the coating zone in precision coating depended on a strong suction, whereas in Wurster coating, pellets were transported by a combination of peripheral fluidization, gravity, and weak suction pressure. In precision coating, MFR was found to increase uniformly with air flow rate and atomizing pressure, whereas MFR in Wurster coating did not correlate as well with air flow rate and atomizing pressure. This demonstration showed that transport in precision coating was air dominated. In conclusion, fluid dynamics in precision coating was found to be air dominated and dependent on pressure differential, thus it is more responsive to changes in operational variables than Wurster coating.

KEYWORDS: fluid bed coaters, coating, flow, pellets.

INTRODUCTION

Coating of particles is an important unit operation in the pharmaceutical industry. There are numerous applications of coating, including drug layering, modified release coating, physical and chemical protection, aesthetic purposes, taste masking, and enhanced identification of drugs.[1-4]

Wurster coaters[5] are bottom spray fluid bed coaters that have been extensively used in the pharmaceutical industry for coating of small particulates, especially pellets.[1] They offer excellent heat and mass transfer within the product bed and are able to form uniform coats.[2] However, their use has been limited by the propensity of the particles to agglomerate during the coating process.[6] This poses a limit on the spray rate and sizes of particles that can be coated. Thus, various modifications to the conventional Wurster coaters have been made to improve the coating process.

The Precision coater[7] (GEA-Aeromatic Fielder, Eastleigh Hampshire, UK) is similar to the Wurster coater except for its mode of air distribution. The air distribution plate in the Precision coater consists of a perforated plate connected to the Swirl Accelerator (GEA-Aeromatic Fielder, Eastleigh Hampshire, UK). The Swirl Accelerator functions to swirl and accelerate the inlet air to impart spin and high velocity to the particles as they transit through the partition column where coating takes place. This process can change the fluid dynamics of the particles.

In bottom spray fluid bed processes, the area of the air distribution plate directly under the partition column has more perforated area than the periphery region of the air distribution plate, resulting in a higher central air velocity through the partition column.[2] This creates a region of lower pressure that draws in particles by the Venturi's effect and lifts particles up the partition column (up-bed zone) according to Bernoulli's law. As such, particles from the product bed enter the partition column (horizontal transport zone) and decelerate in the expansion chamber (deceleration zone)—falling outwards freely in an inverted U-shape trajectory back onto the product bed staging area (down-bed zone). The particles then reenter the partition column though the partition gap and repeat the fountain-like cyclic flow.[1] Particles receive coating droplets during the passage through the spray zone within the partition column, and this cycle is repeated until the desired coating level is achieved.

Fluid dynamics was found to be important in controlling product quality and productivity in bottom spray fluid bed coaters.[8,9] The aim of this study was to compare the fluid dynamics in Wurster coating and swirl accelerated air (precision) coating performed under standardized conditions. This study would enhance the knowledge of mechanisms affecting transport of particles and help to assess the possible effects on performance of coating in these processes. The influence of coater configuration (partition gap, air distribution plates, accelerator inserts) and operating conditions (pellet load, pellet size, air flow rate, atomizing air) were studied.

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Several methods have been used to quantify and describe the fluid dynamics of particles in fluid beds, including positron emission particle tracking,[10,11] radioactive particle tracing,[12] magnetic particle tracing,[9,13] and optical fiber probe techniques.[14] Owing to high cost and technological complexity of the reported methods, a new and much simpler method using a pellet collection system to determine the pellet mass flow rate (MFR) was explored in this study to describe the fluid dynamics of particles in fluid bed coaters. There were certain limitations identified with this method, in particular the subjective assessment of the end-point and non-steady-state measurements. However, because this was a comparative study performed under similar conditions, equipment-related differences were minimized. Moreover, the air handling system was quick to reach steady-state conditions within a few seconds, so the initial startup had minimal effect on the overall experimental results. Hence this method was still explored because of its potential usefulness in the characterization of particle fluid dynamics in these coaters.

Materials and Methods

Materials

Spherical, smooth, sugar pellets of size fractions, 710 to 850 μm and 500 to 600 μm, were obtained for this study (Nonpareil seeds, JRS Pharma LP, Patterson, NY). Hypromellose (Methocel-E3, Dow Chemical, Midland, MI) and polyvinyl pyrrolidone (Plasdone C-15, ISP Technologies, Wayne, NJ) were used as the coating materials.

Equipment

Wurster coating and precision coating were performed using the Aerocoater and Precision coater (GEA), respectively, which were fitted with the same air handling system (MP-1 Multi-processor, GEA), partition column (8-cm diameter and 25-cm height), and conical acrylic coating chamber. The spray nozzle used in both coaters had similar nozzle tip diameters (1 mm), nozzle tip protrusions (1 mm from the flushed position), and air cap opening diameters (2.5 mm) (Figure 1).

In Wurster coating, 3 different air distribution plates were studied. These included 2% and 6% open area plates with circular holes, 3 mm in diameter. These were used in conjunction with a Tressen mesh to prevent the product from falling through the holes. The third was a Feidler plate, which is a solid plate with an open area of 2%. The holes of the Feidler plate were bicylindrical such that the diameter on the airside was 1.6 mm and on the product side, 0.71 mm. All 3 air distribution plates were funnel-shaped with similar inclination. The open area was defined as the area of the periphery of the air distribution plate, which was perforated.

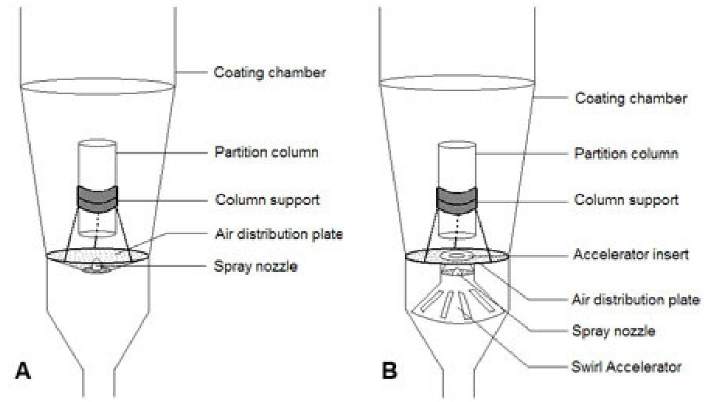

Figure 1. Diagram of the (A) Aerocoater and (B) Precision coater.

In precision coating, the standard air distribution plate was used. It consisted of a horizontal perforated plate attached to the Swirl Accelerator (Figure 1B). This plate had a graduated open area from 2% on the outside to 1.5%, 1%, 0.5%, and 0%. The holes were tapered with a diameter of 0.8 to 1.0 mm airside and 0.7 mm product side. The accelerator insert, a detachable solid cylinder with an opening in the middle, made up the central part of the air distribution plate. Accelerator inserts used in precision coating had openings with diameters of 20, 24, 30, and 40 mm. Those with smaller openings would generate higher air velocities at the same air flow rates following the law of conservation of mass.

Base-coating of Pellets

The 2 size fractions of sugar pellets were film-coated separately prior to mass flow rate determination to reduce their friability. Pellets were coated by Wurster coating to 2% wt/wt weight gain with an aqueous solution of 5% wt/wt hypromellose and 1% wt/wt polyvinyl pyrrolidone. Coated pellets were further dried at 60°C for 12 hours in a hot air oven and sieved to remove any fines and agglomerates. After coating, coated pellets remained unchanged in their respective size fractions, 500 to 600 μm or 710 to 850 μm, as only very thin coats were applied onto the pellets.

Characterization of Coated Pellets

Angle of repose, α_r, angle of fall, α_f, and angle of difference, α_d, of the coated pellets were determined using a powder tester (Hosokawa PT-N, Osaka, Japan). Pellets were fed through a funnel onto a fixed base, forming a cone. The cone was caused to collapse by three falls of a steel weight of 104.3g, guided by a pole over 160mm vertical distance and located at 85mm from the center of cone. An angle pointer was used to determine the angles of inclination of the initial cone (α_r) and collapsed cone (α_f). The α_d was derived from the difference between the α_r and α_f. Five measurements were obtained for each sample.

Pellet bulk density, ρ_b, and tapped density, ρ_t, and Hausner ratio (an index for flowability) were determined using a *United States Pharmacopeia (USP)* tap density tester (Sotax TD2, Allschwil/Basel, Switzerland) following the *USP* method.[15] ρ_b, ρ_t, and Hausner ratio[16] were defined as follows:

$$\rho_b = \frac{w}{100} , \quad (1)$$

$$\rho_t = \frac{w}{v_f} , \quad (2)$$

$$Hausner\ Ratio = \frac{\rho_t}{\rho_b} , \quad (3)$$

where w was the weight of pellets made up to 100 mL before tapping, and v_f was the final volume of pellets after tapping.

Images of 30 randomly chosen pellets of each size fraction were obtained using a stereomicroscope (SZH, Olympus, Tokyo, Japan) linked to an image analysis program (Micro-image, Olympus Japan). Sphericity was determined from the cross-sectional area (A) and perimeter (P) of the pellets using the following equation:

$$Sphericity = \frac{4\pi A}{P^2} \quad (4)$$

The physical properties of the base-coated pellets are presented in Table 1. Smaller pellets (500-600 μm) had significantly poorer flow and packing properties than the larger pellets (710-850 μm) (P < .05) albeit both have very good flow properties and similar sphericities.

Determination of Pellet Mass Flow Rate

The pellets were placed in the coating chamber and leveled. The pellet collector consisted of fine netting (mesh size 180 μm) held by a metal frame and was fitted above the pellet bed between the partition column and internal wall of the chamber (Figure 2A[i] and 2B[i]). During each run, the air flow and atomizing air were activated simultaneously, transporting the pellets from the product bed to the pellet collector. The pellet collector served to collect the pellets, preventing further cycling of the pellets (Figure 2A[ii] and 2B[ii]). The time (t) taken for a certain pellet load (M) to flow into the pellet collector was determined, and the mass flow rate (MFR) calculated as follows:

$$MFR = \frac{M}{t} \quad (5)$$

Table 1. Physical Properties of Base-coated Pellets*

Parameters	Size of Pellets, μm	
	500-600	710-850
Angle of repose (°)†	31.4 ± 0.3	30.1 ± 0.5
Angle of fall (°)†	23.6 ± 1.3	21.1 ± 0.8
Angle of difference (°)†	7.8 ± 1.6	9.0 ± 0.9
Bulk density, g/L†	864 ± 18	874 ± 9
Tapped density, g/L†	907 ± 15	888 ± 4
Hausner ratio†	1.05 ± 0.02	1.02 ± 0.01
Sphericity	0.89 ± 0.01	0.89 ± 0.01

*Values are given as mean ± SD, n = 5.

†Two sample *t*-test showed significant difference in means (P < .05).

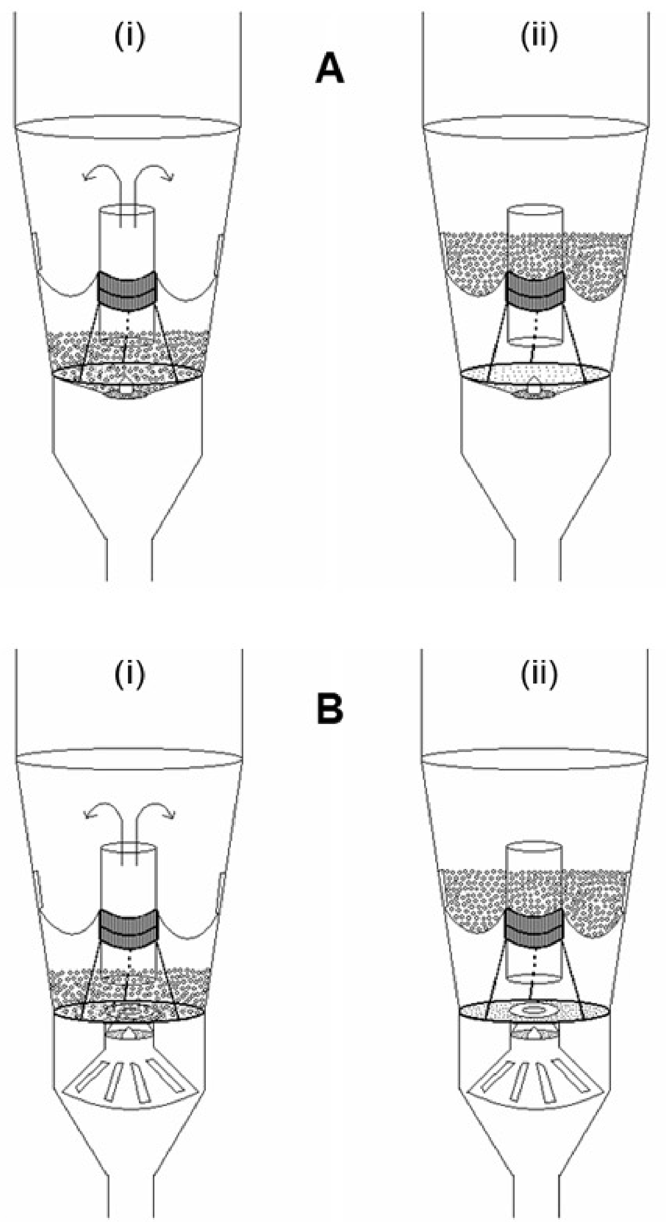

Figure 2. Schematic diagram of pellet flow in 1 cycle in (A) Wurster coating and (B) precision coating using the pellet collector.

The ranges of parameters studied are listed in Table 2. Unless specified, size of pellets used was in the range of 710 to 850 μm, a pellet load of 700 g was used, the Wurster coater was fitted with the Feidler plate with partition gap of 18 mm, and the precision coater was fitted with a 24-mm diameter accelerator insert with partition gap of 10 mm. In all the tests, MFR were determined at a minimum and maximum air flow rate (AF) and atomizing pressure (AP). For simplicity, processing conditions are denoted as AF(*x*)AP(*y*), where *x* represents the air flow rate (m^3/h), and *y* represents the atomizing pressure (bar). Minimum conditions were defined as AF(80)AP(1), and maximum conditions as AF(120)AP(3). All runs were performed in triplicate.

Since the aim of this study was to quantify the pellet MFR in order to assess the flow dynamics in the 2 coaters, all experiments were conducted without liquid spray to avoid confounding factors such as changes in flow properties and weight of pellets. The experiments were performed in a controlled environment of ~25°C and 50% relative humidity (RH).

High Speed Photography

A high speed camera (Motionpro HS-4, Redlake, AZ) was used to capture images of pellets moving up a transparent acrylic partition column in both coaters. Images were captured at 2770 frames per second under similar conditions of air flow rate (60 m^3/h) and partition gap (18 mm), using pellets of size ranging from 710 to 850 μm. Using slow speed playback, 30 randomly chosen pellets were individually tracked to determined the time taken to move over a fixed distance.

Statistical Tests

Differences between points were analyzed by SPSS 12.0 (SPSS Inc, Chicago, IL) using independent samples *t*-test with a confidence interval of 95%.

Table 2. Process Parameters and Their Ranges Studied

Process Parameter	Setting
Partition gap, mm	4-22
Air inlet diameter of accelerator inserts used in precision coating, mm	20, 24, 30, 40
Types of air distribution plate used in Wurster coating	Feidler plate (2%) Open area plate (2%, 6%)
Air flow rate, m^3/h	80, 90, 100, 110, 120
Atomizing pressure, bar	1, 1.5, 2, 2.5, 3
Pellet size, μm	500-600, 710-850
Pellet load, g	500, 700, 850, 1000

Results and Discussion

In this study, the time taken for a fixed load of pellets to move through the partition column was determined using the pellet collection system (Figure 2). The MFR in precision coating was generally lower than in Wurster coating, while the pellet velocities determined from high speed photography were higher for precision coating (5.3 ± 1.1 m/s) than for Wurster coating (1.5 ± 0.2 m/s) under similar conditions. This result showed that MFR values did not represent mean pellet velocities but rather the density of pellets moving up the partition column as illustrated in the photographs captured by the high speed camera (Figure 3).

Influence of Partition Gap on Mass Flow Rate

The partition gap may be defined as the vertical distance between the bottom of the partition column and the surface of the air distribution plate. It was recognized as an important factor in determining the success of coating of small particles[17] and was found to affect the drug release profile of coated pellets.[18] This finding was attributed to its influence on the flow of pellets into the partition column and the exposure of pellets to the coating droplets in the spray zone.[9,11]

For both Wurster coating and precision coating, the MFR increased, reached a peak, and decreased with increasing partition gaps (Figures 4 and 5). The partition gap was like a passageway for the pellets. When the partition gap was too large, there might be insufficient pressure differential to draw particles up the partition column.[17] As the passageway was constricted by narrowing the partition gap, the pellets moved at a faster velocity through the partition gap by Venturi's effect. However, when the partition gap was too small, it could have restricted the passage of pellets.

The ranges of MFR in precision coating were significantly greater than that of Wurster coating when the partition gap was varied (Figures 4 and 5). Therefore, adjustment of partition gap could be more crucial in controlling MFR in precision coating than in Wurster coating, whereby MFR was not as sensitive to changes in partition gap. As partition gap was known to affect the pressure differential across the partition gap, its greater influence on MFR in precision coating indicated that the mechanism of transport of pellets in precision coating was more dependent on the pressure differential across the partition gap than in Wurster coating. Pellet flow in the latter could have occurred from the blowing of the pellets up the partition column by inlet air.

MFR in the precision coating was significantly lower than Wurster coating at the same conditions of AF and AP (Figures 4 and 5), indicating that pellet flow through the partition column in precision coating was scarcer than in Wurster coating. This phenomenon was observed visually

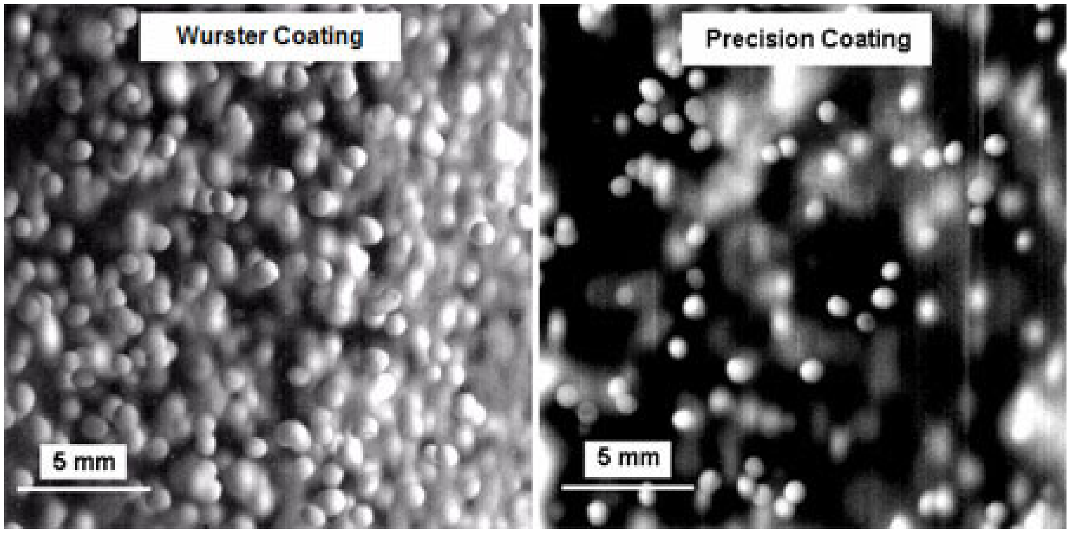

Figure 3. Photographs of pellets moving within the partition column in Wurster coating and precision coating over an area of 2 cm × 2 cm.

and also in the images obtained by high speed photography (Figure 3). The scarcer flow may indicate that there was better particle separation, which could lead to reduced agglomeration. However, coating material may be lost to the surrounding partition column wall or spray-dried and not deposited onto the particle surfaces. The higher MFR in the Wurster coating might be beneficial in increasing the exposure of pellets to the spray zone. On the other hand, it could increase the propensity to agglomerate during coating if the pellets were too close in the partition column.

Moving from low to high air flow conditions, MFR increased in both coating processes but had the same trend (Figures 4 and 5). This finding showed that increasing air flow conditions increased the rate at which pellets transited through the partition gap without affecting the mechanisms of pellet flow. There was an increase in the optimal partition gap in precision coating when the processing conditions were higher (Figure 5), whereas there was no significant change in optimal partition gap in Wurster coating (Figure 4). At AF(80)AP(1), optimal partition gap in precision coating fitted with the 20-mm accelerator insert was 8 mm and increased to 16 mm at AF(120)AP(3) (Figure 5). As described earlier, pressure differential appeared to have a greater influence in precision coating than Wurster coating for the transport of pellets into the coating zone. Hence, it may be inferred that the optimal partition gap was dependent on the strength of pressure differential across the partition gap. Also, an increased pressure differential with air flow rate probably enabled correspondingly more pellets to enter the spray zone and be lifted up the partition columns.

When the partition gap was further increased beyond the optimal point, a maximum gap was reached. Beyond this

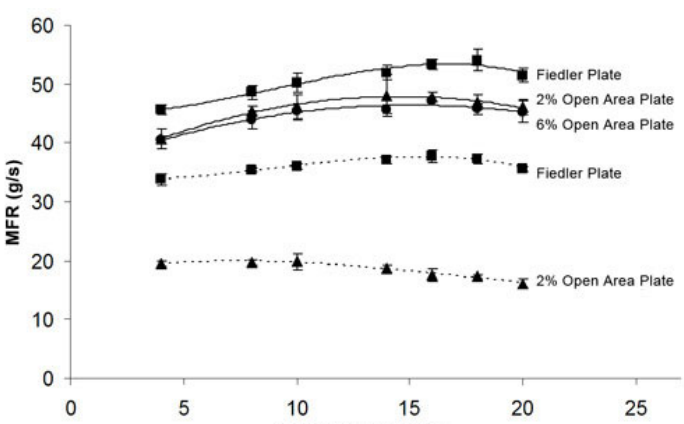

Figure 4. Influence of partition gap on MFR in Wurster coating using ■: Feidler plate, ▲: 2% open area plate and ●: 6% open area plate at AF(80)AP(1) (represented by dotted lines) and AF(120) AP(3) (represented by solid lines) (mean ± SD, n = 3; pellet size = 710 to 850 µm; pellet load = 700 g; partition gap = 18 mm).

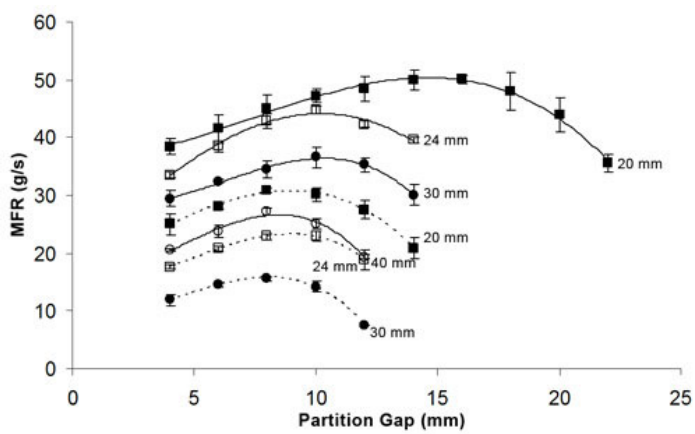

Figure 5. Influence of partition gap on MFR in precision coating using accelerator inserts of inlet diameters ■: 20 mm, □: 24 mm, ●: 30 mm, and ○: 40 mm at AF(80)AP(1) (represented by dotted lines) and AF(120)AP(3) (represented by solid lines) (mean ± SD, n = 3; pellet size = 710 to 850 µm; pellet load = 700 g; partition gap = 10 mm).

partition gap, MFR values could not be determined because significant amount of pellets failed to pass into the pellet collector and the cycle time could not be determined. This result was attributed to the decreased pressure differentials generated at higher partition gaps. The maximum partition gap was generally higher in Wurster coating than in precision coating (Figures 4 and 5). This finding showed that the decrease in pressure differential had less influence on pellet transport in Wurster coating than in precision coating. The sloping funnel-shaped air distribution plate in Wurster coating facilitated pellet flow toward the partition column, and the center of the air distribution plate was perforated allowing air to push the pellets up the partition column, making transport of pellets less reliant on pressure differential. In precision coating, the air distribution plate was horizontal and the accelerator insert was nonperforated, except for the center opening, making transport of pellets dependent on the high central air velocity, which generated the pressure differential across the partition gap to draw pellets inward and up the partition column.

Influence of Air Distribution Plates on Mass Flow Rate in Wurster Coating

In Wurster coating, there were little changes to the MFR at different partition gaps when the type of air distribution plate was varied (Figure 4). MFR obtained with the Feidler plate was significantly higher than the 2% and 6% open area plates, which were not found to be significantly different under high air flow conditions (Figure 4). Under low air flow conditions, the Feidler and 2% open area plates were clearly different but MFR for 6% open area plate could not be determined because of very poor pellet flow conditions.

There was little difference in the MFR obtained using 2% and 6% open area plates, indicating that the percentage of open area in the periphery of the air distribution plate had little real influence on the transport of pellets into the spray zone below the partition column. The 2% open area plate and the Fiedler plate had similar open areas, but the MFR obtained with the Fiedler plate was significantly higher. The main difference between the latter 2 plates was the material used for the central part of the air distribution plate directly under the partition column. As mentioned earlier, this was an area with more perforations than the periphery of the air distribution plate. The central part of the Feidler plate consisted of a simple mesh with pore size of ~200 µm and ~36% perforation, whereas the central area in the open area plates consisted of interlocking Tressen mesh, which probably imparted greater resistance to air flow and hence a lower MFR. The same Tressen mesh was used with both open area plates, thus explaining their similarities in MFR. This showed that MFR was influenced by the properties of the center part of the air distribution plate more than the periphery. Another feature that contributed to the better performance of the Feidler plate was the directional air flow created by the bicylindrical apertures which helped with the movement of pellets in the periphery downbed region.

Influence of Accelerator Inserts on Mass Flow Rate in Precision Coating

In precision coating performed with the different accelerator inserts, MFR were found to be related to partition gaps by cubic equations with high correlation factors ($R^2 > 0.98$). MFR obtained with the 20-mm accelerator insert was the highest, followed by the 24-, 30-, and 40-mm accelerator inserts (Figure 5). MFR using the 40-mm accelerator insert could not be determined at AF(80)AP(1) because the flow was too poor. This effect was also observed from a study using optical probe technique in a conical spouted bed, where the solid cycle rate and solid cross-flow into the spout decreased with an increase in air inlet diameter.[14] Accelerator inserts with smaller inlet diameters generated higher air velocities, which increased the pressure differential across the partition gap. This phenomenon would impart greater acceleration to particles passing through the spray zone, possibly reducing agglomeration. However, high air velocities may cause particles to hit onto the top of the chamber causing attrition.

Influence of Pellet Load on Mass Flow Rate

Linear relationships ($R^2 > 0.99$) exist between MFR and pellet load in Wurster coating and precision coating (Figure 6). This behavior was also seen in a conical spouted bed, where the solid flow rate increased with increasing stagnant bed height.[14] This finding was probably due to the result of

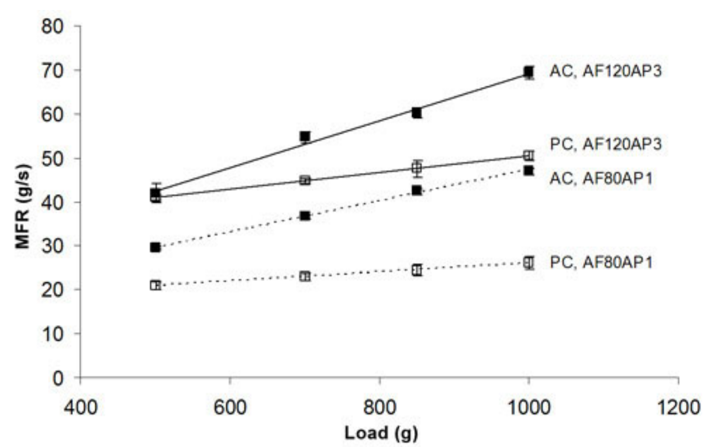

Figure 6. Influence of pellet load on MFR in ■: Wurster coating and □: precision coating at AF(80)AP(1) (represented by dotted lines) and AF(120)AP(3) (represented by solid lines) (mean ± SD, n = 3; pellet size = 710 to 850 µm; partition gap = 18 mm and 10 mm, respectively).

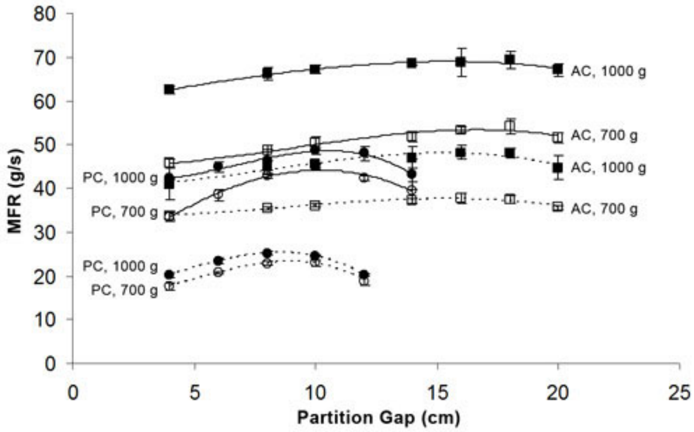

Figure 7. Influence of partition gap on MFR using pellet load of □: 700 g, ■: 1000 g in Wurster coating, and ○: 700 g, ●: 1000 g in precision coating at AF(80)AP(1) (represented by dotted lines) and AF(120)AP(3) (represented by solid lines) (mean ± SD, n = 3; pellet size = 710 to 850 µm; partition gap = 18 mm and 10 mm, respectively).

the increased "hydrostatic pressure" of the increased load, which pushed the pellets through the partition gap. The MFR increased to a significantly greater extent in Wurster coating than in precision coating, showing a greater influence of "hydrostatic pressure" on transport of pellets. This indicated that Wurster coating was more dependent on the feeding of pellets to the partition gap for transport, a contributory factor being the sloping air distribution plate. This showed that flow properties of the substrate played an important role in particle transport in Wurster coating. The minimal effect of "hydrostatic pressure" on MFR in precision coating further substantiated its dependence on pressure differential for transportation, whereby transport would be limited by pressure differential. Suction by differential pressure may offer more controlled particle movement; however, there may be greater difficulties when processing larger particles.

The effect of hydrostatic pressure is also shown in Figure 7, where the effect of partition gap on MFR was studied using 700 and 1000 g of pellets in both coaters. Optimal partition gaps were similar between the 2 loads in both coaters, suggesting that they were not affected by change in load.

Influence of Pellet Size on the Mass Flow Rate

In Wurster coating, larger pellets (710-850 µm) had slightly lower MFR than smaller pellets (500-600 µm) at low air flow conditions (Figure 8). This was in agreement with the findings of Fitzpatrick et al, which showed that larger tablets had longer cycle times than smaller tablets at the same conditions in a tabletop Wurster coater. This result was also observed in a conical spouted bed using glass spheres of different sizes.[14] This behavior can be explained by Newton's Second Law of Motion, whereby acceleration is proportional to the force exerted and inversely proportional to the mass of the object. When higher air flow conditions were used, contrasting results were observed (Figure 8). Smaller pellets had similar MFR as bigger pellets despite the higher central acceleration as explained by Newton's Second Law of Motion. This may be owing to the higher trajectories of smaller pellets at high air flow conditions, causing them to be suspended in air for a longer time before finishing a cycle. Although this phenomenon may aid in drying of the particles, it may also cause the substrate bed height to decrease excessively, resulting in scarce pellet flow through the partition column and over-wetting. Of greater significance was the "air curtain" effect created in the Wurster coater. As the increased air flow rate affected mainly air flow peripheral to the spray nozzle, there was the development of an effective air curtain effect at the peripheral region of the spray zone as the air flow rate was increased. This prevented the pellets from moving through the partition gap. Smaller pellets tended to be more affected by this air curtain effect and faced greater difficulties traversing from the peripheral staging area into the spray zone and partition column.

In precision coating, MFR of both sizes of pellets were similar at both air flow conditions. Conditions governing material mass flow in precision coating were less affected by small differences of individual particle characteristics and more dominated by mass conveyance effects contributed by the increased air flow rate. However, the optimal partition gaps obtained with the different sizes were different (Figure 8). The higher optimal partition gaps of smaller pellets probably resulted from the poorer flow, which caused greater resistance while passing through the partition gap as

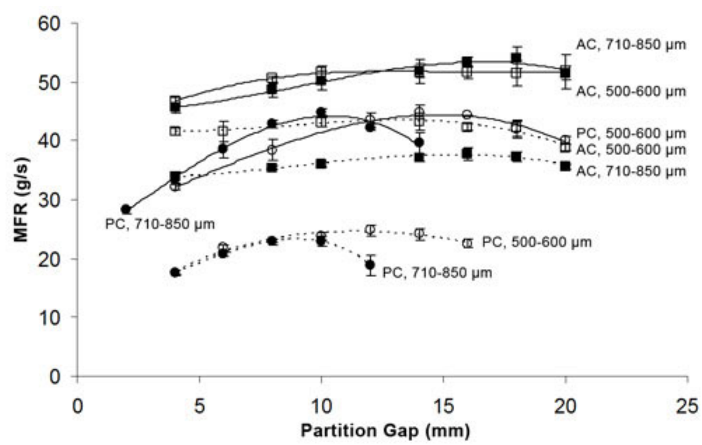

Figure 8. Influence of partition gap on MFR using pellet size of □: 500 to 600 µm, ■: 710 to 850 µm in Wurster coating and ○: 500 to 600 µm, ●: 710 to 850 µm in precision coating at AF(80)AP(1) (represented by dotted lines) and AF(120)AP(3) (represented by solid lines) (Mean ± SD, n = 3; pellet load = 700 g; partition gap = 18 mm and 10 mm, respectively).

compared with the larger pellets. The lower mass of smaller pellets would enable transport of pellets through the partition column at lower pressure differentials, hence resulting in larger optimal partition gaps.

Influence of Air Flow Rate and Atomizing Pressure on Mass Flow Rate

AF and AP are the main forces resulting in the pneumatic transport and drying of coated particles in bottom-spray coaters. AF is adjusted mainly to enable adequate fluidization, drying, and movement of particles up the partition column, and AP to break up the liquid spray into small droplets.[11] Excessively high AF and AP may result in attrition and increase spray-drying effect. Therefore, AF and AP have to be appropriately adjusted to suit the particles to be coated. Here, we assumed that the AP in both coaters were comparable as the dimensions of the nozzle and the source of compressed air were similar.

For both coaters, the MFR increased with increasing AF and AP. The increase in MFR in Wurster coating reached a maximum and could not be further increased by increasing AF and AP (Figure 9A). There appeared to be an all-or-none situation, where MFR was relatively independent of AF and AP. Manipulation of AF and AP would not be useful for adjusting flow of pellets for efficient coating.

In the precision coating, MFR was proportional to the AF and AP (ie, pellet transport was air-dominated) (Figure 9B). MFR could therefore be adjusted by varying AF and AP according to the needs of a particular run. This finding further substantiated the primary mechanism by which pellets were drawn into the partition column, namely, pressure differential generated across the partition column. As increasing AF and AP would be expected to cause a proportional increase in pressure differential across the partition column, the lift of particles would be increased according to Bernoulli's law.

The trend observed with an increase in AF in Wurster coating was also observed in other Wurster coaters.[9,11] Fitzpatrick et al determined the cycle time of tablets in a tabletop Wurster coater using positron emission particle tracking. The results showed that the mean cycle time decreased at a decreasing rate with an increase in AF. The same trend was seen in another study using magnetic tracing technique, where the tablet cycle time was obtained during actual coating runs in a Wurster coater.[9]

Increase in AF caused the MFR in the Wurster coater to level off (Figure 9A). This trend could be owing to the effect of the funnel-shaped air distribution plate on the flow of the pellets (Figure 1A), which was also seen in the findings of Shelukar et al. At low AF, the slope of the funnel-shaped air distribution plate greatly enhanced the movement of the pel-

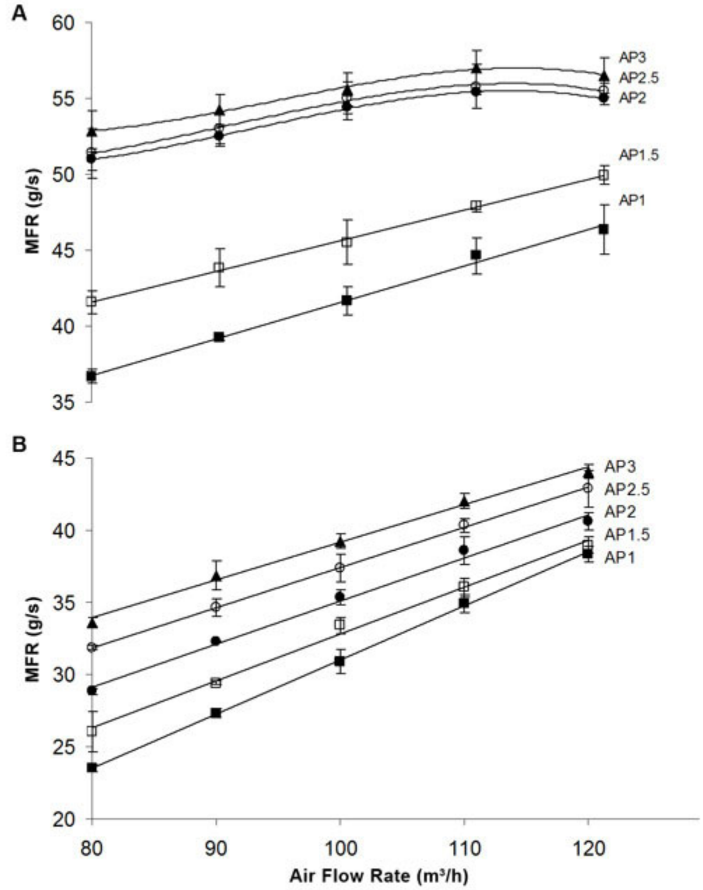

Figure 9. Influence of AF on MFR at AP of ■: 1, □: 1.5, ●: 2, ○: 2.5, and ▲: 3 bars in (A) Wurster coating and (B) precision coating (mean ± SD, n = 3; pellet size = 710 to 850 μm; pellet load = 700 g; partition gap = 18 mm and 10 mm, respectively).

lets, contributing to the geometric increase in MFR. When higher AF were used, the pressure differential across the partition gap increased; however, pellet flow could be then limited by the resistance of pellet flow through the partition gap by the counteracting air curtain effect as explained earlier.

In Wurster coating, AP contributed little to the MFR at low AP of below 1.5 bar, as was also seen in the study carried out by Fitzpatrick et al., 2003.[11] When the AP was increased, there appeared to be a sudden increase in MFR followed by leveling off in MFR (Figure 9A). This leveling off was only observed in Wurster coating and not in precision coating (Figure 9B). The spray nozzle in Wurster coating was set higher relative to the product bed than in precision coating. When higher AP were used, the air pressure could be so strong as to create an outward pressure to the entry of product into the partition column, limiting the flow of pellets from the staging product bed into the partition column. AP above 1.5 bar was the limiting velocity beyond which the MFR was largely unaffected.

The above explanations for the trends observed with increasing AF conditions in Wurster coating and precision coating supported the postulation that the mechanisms of transport in precision coating occurred primarily by pressure differential across the partition gap and in Wurster coating, by pellet flow/blowing to the partition column. The precision coater was shown to be an air-dominated coater as the effects of good air flow dynamics and swirling effects on the air had improved conditions for the flow of pellets in the coater.

CONCLUSION

The results of this study strongly suggested that the mechanism of particle transport in Wurster coating was owing to both gravity feeding and weak suction of particles into the partition column by inlet air; while in precision coating, feeding into the partition column was governed largely by suction pressure created by pressure differential. Hence, for precision coating, changes in either air flow rate or atomizing pressure has a direct linear effect on product flow. Pellet flow in Wurster coating was found to be denser and slower than precision coating at the coating zone (within the partition column), suggesting that the extent of agglomeration is likely to be much greater in Wurster coating. Thus, knowledge of fluid dynamics in the 2 processes enabled better understanding of their possible impacts on the coating process.

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