Available online at www.sciencedirect.com
ScienceDirect
International Journal of Pharmaceutics 350 (2008) 172–180
INTERNATIONAL JOURNAL OF PHARMACEUTICS
www.elsevier.com/locate/ijpharm

Drying efficiency and particle movement in coating—Impact on particle agglomeration and yield

E.S.K. Tang, L. Wang, C.V. Liew, L.W. Chan, P.W.S. Heng *

Department of Pharmacy, Faculty of Science, National University of Singapore, 18 Science Drive 4, Singapore 117543, Singapore

Received 8 May 2007; received in revised form 8 July 2007; accepted 25 August 2007
Available online 4 September 2007

Abstract

The purpose of this study was to determine the influences of drying efficiency and particle movement on the degree of agglomeration and yield of pellets coated under different conditions. Thermodynamic conditions were varied using different inlet air temperatures and airflow rates, fluid dynamics were varied using different airflow patterns and air velocities, and two sizes of pellets were coated at different airflow rates and partition gaps. Agglomeration was minimized when all the moisture introduced into the system was removed by the drying air. Excessively dry conditions led to increased loss of yield due to spray-drying effect and attrition. Fluid dynamics were still important even with adequate drying, as the degree of agglomeration was relatively higher in the non-swirling airflow of Wurster coating than in the swirling airflow of precision coating. Increasing air velocities increased pellet velocities, resulting in lower degrees of agglomeration. Hence, agglomeration due to fluid dynamics was attributed to differences in pellet velocities, pellet proximity and pellet trajectories within the partition column. Smaller pellets agglomerated primarily from inadequate drying and not due to inadequate opportunities for particle movement. Larger pellets were more affected by the partition gap due to restriction of their movement through the partition gap. Hence, both thermodynamics and fluid dynamics were found to be important in minimizing agglomeration and ensuring quality coated products.

Keywords: Coating; Swirl; Drying; Airflow; Agglomeration

1. Introduction

Coating of particles is commonly carried out in the pharmaceutical industry to enhance the properties of the final dosage form. By applying a layer or several layers of coat around the particles, functions such as controlled release, protection against environmental agents, taste masking, reduction of friability and enhancement of appearance can be achieved (Cole, 1995). Smaller coated particles have added benefits such as better distribution in the gastro-intestinal tract (Dechesne and Delattre, 1986), more consistent gastro-intestinal transit rate (Sugito et al., 1990) and less deformation upon compaction into tablets (Johansson et al., 1998) as compared to their larger counterparts. However, the main problem with coating smaller particles is the increased tendency of agglomeration (Jono et al., 2000). Hence, it is important to understand the causes of particle agglomeration in order to overcome it.

In fluid bed coating, particle mixing, spraying of coating material and evaporation of solvent occur concurrently. During the wetting process, liquid bridges can form between the particles and agglomeration takes place if the liquid bridges do not break up but solidify, resulting in the permanent fusion of two or more particles (Hemati et al., 2003). The degree of agglomeration of particles during fluid bed coating can be influenced by factors such as core properties, type of coating materials, process conditions and equipment set-up (Tang et al., 2005).

The thermodynamics or drying condition in the coater is important during coating, as excessively dry environment would lead to spray-drying effect and attrition while over-wetting causes agglomeration (Maronga and Wnukowski, 1998; Ronsse et al., 2007). In this study, drying efficiency was used as the parameter to determine the ability of the coater to handle moisture fed into the system, whereby the amount of moisture removed by the outlet air was expressed as a percentage of the total amount of moisture introduced into the coater.

The fluid dynamics or particle movement during the coating process could also affect the agglomeration tendency of

* Corresponding author. Tel.: +65 65162930; fax: +65 67752265.
E-mail address: phapaulh@nus.edu.sg (P.W.S. Heng).

0378-5173/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpharm.2007.08.047

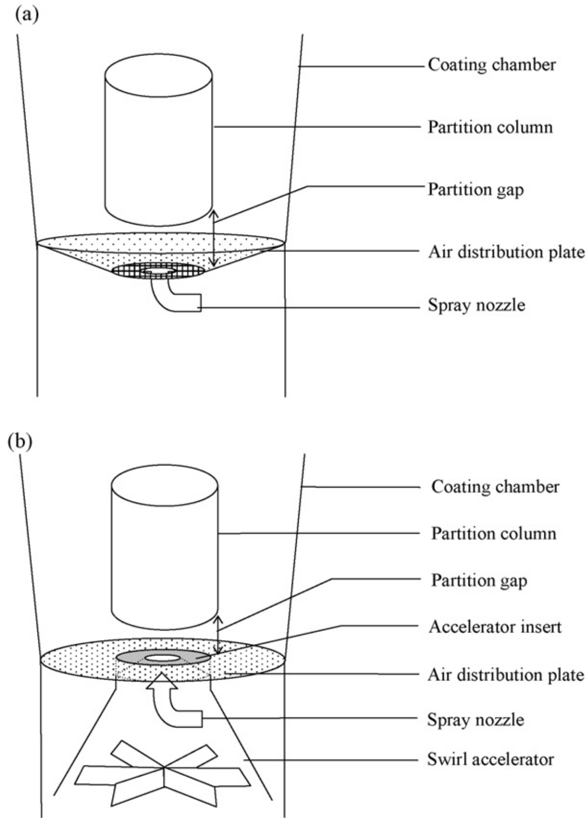

Fig. 1. Diagrams of air distributor plate and associated parts of (a) Wurster coater and (b) precision coater (not drawn to scale).

particles. Wurster and precision coating (Wurster, 1953; Walter, 1998) are both bottom spray fluid bed processes that differ in the mode of air distribution (Fig. 1). In precision coating, the swirl accelerator serves to swirl and accelerate the incoming air to impart spin and high velocity to the particles moving up the partition column. It was suggested in a previous study that Wurster coating transported particles up the partition column by both gravity feeding and weak suction of particles by the inlet air while precision coating transported particles up the partition column primarily by suction pressure created by pressure differential (Chan et al., 2006). Swirling airflow in precision coating has also been found to increase the performance of coating by increasing the coat uniformity and decreasing the degree of agglomeration (Heng et al., 2006). This could be due to the increased flow paths (Yilmaz et al., 2003) and the increased heat transfer (Ozbey and Soylemez, 2005) of the swirling airflow. However, the causes of particle agglomeration under different processing conditions in swirling airflow have not been investigated.

In view of the importance of processing conditions on the eventual product quality, the influences of thermodynamics and fluid dynamics of swirling airflow on agglomeration were investigated. The influence of thermodynamics was studied using drying efficiency at different inlet air temperatures and airflow rates, and the influence of fluid dynamics was studied using particle movement in different airflow patterns and air velocities. The influence of particle size on drying efficiency and agglomeration was also studied to better understand the conditions favorable for coating smaller particles.

2. Materials and methods

2.1. Materials

Sugar pellets (Nu-pareil, Hanns Werner, Tornesch, Germany) of size fractions 355–425 μm (smaller pellets) and 500–600 μm (larger pellets) were used as the cores for coating. Coating material consisted of 5% (w/w) hypromellose (Methocel-E3, Colorcon, NJ, USA) and 1% (w/w) polyvinyl pyrrolidone (PVP-C15, ISP Technologies, New Jersey, USA) in deionised water. Precision coating (Precision Coater, GEA-Aeromatic Fielder, Eastleigh, UK) or Wurster coating (Aerocoater, GEA-Aeromatic Fielder, Eastleigh, UK) was carried out with the same air handling system (MP-1, GEA-Aeromatic Fielder, Eastleigh, UK). Each coater had a two-fluid spray nozzle with nozzle tip diameter of 1 mm, air cap opening diameter of 2.5 mm and nozzle tip protrusion of 1 mm from the flushed position. The air distribution plate for Wurster coating consisted of a 2% open area Feidler plate.

2.2. Methods

2.2.1. Base coating of pellets

Batches of 3 kg of pellets were coated with a thin base coat (2%, w/w weight gain) prior to subsequent coating trials to minimize the influence of core properties on the coating process. Wurster coating at airflow rate (AF) of 80 m^3/h, atomizing air pressure of 2 bar, spray rate of 14 g/min and partition gap (PG) of 18 mm was used for base coating. Base-coated pellets were tray-dried at 60 °C for about 12 h in a hot air oven and sieved to remove any fines and agglomerates prior to being used. Sieves with mesh sizes of 355 and 500 μm were used for the smaller pellets and 500 and 710 μm mesh sizes for the larger pellets.

2.2.2. Coating of pellets

For each coating run, 1 kg of base-coated pellets were coated with 1 kg of coating material (6%, w/w weight gain) at a spray rate of about 14 g/min and atomizing air pressure of 1.5 bar. Process parameters used with the larger pellets are listed in Table 1. Two 2^2 factorial designs were carried out to study the effects of pellet size and AF and the effects of pellet size and PG (Table 2). Unless specified, process conditions marked with asterisks (*)

Table 1
Process parameters studied in the respective coating processes

Process parameters	Coating process	Settings
Inlet air temperature, T_p (°C)	Precision coating	60, 65, 70*, 75, 80
Airflow rate, AF (m^3/h)	Precision coating	60, 70, 80*, 90, 100
Partition gap, PG (mm)	Wurster and precision coating	14, 18*, 22
Accelerator insert (AI) diameter (mm)	Precision coating	20*, 24, 30

* These were values kept constant when other parameters were varied.

Table 2
Factorial designs for the comparison of pellet size and AF or PG

Factorial design 1		Factorial design 2	
Pellet size (μm)	AF (m^3/h)	Pellet size (μm)	PG (mm)
355–425	60	355–425	6
355–425	80	355–425	18
500–600	60	500–600	6
500–600	80	500–600	18

in Table 1 were used as the standardized conditions for all runs. At least two coating runs were carried out for each experimental condition.

2.2.3. Determination of process conditions

During pellet coating, process conditions including inlet air relative humidity, inlet air temperature (T_p), outlet air temperature and outlet air relative humidity were continuously recorded. The relative humidity was measured using humidity transmitter (I-1000, Rotronic Instruments, West Sussex, UK) and temperature was measured using dry bulb temperature element (PT-100, Testtemp, West Sussex, UK). Measurements were taken every 10 s with a data acquisition system (Orchestrator Ver. 2.5.0.0., Measuresoft Development, Dundalk, Ireland) linked to the MP-1. The coating system was pre-heated at standardized conditions (T_p of 70 °C, AF 80 m^3/h) for 30 min prior to coating. A baseline calibration of inlet and outlet conditions was carried out before the start of coating. Inlet ambient air was maintained at about 50% RH and 25 °C.

2.2.4. Determination of drying efficiency

The drying efficiency (DE) was defined as the ability of the incoming air to remove the moisture introduced into the system and was calculated by the following equation:

$$\mathrm{DE}\,(\%) = \frac{m_g X_o}{m_g X_i + m_l} \times 100 \quad (1)$$

where m_g was the airflow rate (kg/h), m_l the liquid flow rate (kg/h), X_i the inlet air absolute humidity (kg/kg dry air), X_o was the outlet air absolute humidity (kg/kg dry air). The process conditions used for analysis were taken from 20 to 60 min after the start of the run, whereby the conditions had stabilized. The absolute humidity was determined from the psychrometric chart of water–air system at 1 atm pressure using dry bulb temperature and relative humidity (Shallcross, 1997).

2.2.5. Determination of pellet velocities

Images of pellets moving within the partition column were captured by a high-speed camera (Motionpro HS-4, Redlake, AZ, USA) as the partition column was where pellets were coated as they moved through the spray zone. The images were taken at 4000 frames per second over a square area of 10 mm × 10 mm, 80 mm from the base of the air distribution plate. This was carried out by using transparent acrylic partition column and coating chamber, which enabled photography from outside of the coater. The images were captured without spraying the coating material to avoid blurring of the images from coat deposition on the partition column. Pellet velocity (PV) was determined by tracking the speeds of 30 randomly chosen pellets using slow speed playback. Only pellets that were moving upwards were tracked.

2.2.6. Determination of air velocities

Air velocities within the partition column in precision coating were measured using a micromanometer (Model 8705 DP-CALC Micromanometer, TSI, MN, US). Measurements were taken at AF of 80 m^3/h, atomizing air pressure of 1.5 bar and PG of 18 mm at AI diameter of 20, 24 or 30 mm. The probe was placed vertically in the direction of airflow with the tip positioned in the center of the partition column or at the periphery of the partition column (30 mm from the center and 10 mm from the wall of the partition column). Three readings were obtained for each AI diameter.

2.2.7. Determination of degree of agglomeration and yield of coated pellets

After coating, the pellets were weighed and passed through sieves of mesh sizes 355 and 500 μm for the smaller pellets and 500 and 710 μm size for the larger pellets. The degree of agglomeration (Agg) was determined as the percentage of pellets retained by the larger mesh size sieve to the total weight of coated pellets. The yield (Yd) was determined as the percentage of the total weight of coated pellets to the sum of the weight of the initial pellet load and total solid content of coating material sprayed.

2.2.8. Statistical analysis

One-way ANOVA with Tukey's post hoc analysis was used as the statistical test for means. Sample means were significantly different if $p < 0.05$.

3. Results and discussion

3.1. Influence of thermodynamics on drying efficiency, agglomeration and yield

Temperature and airflow rate contribute to the overall drying capacity of the inlet air. By varying these factors, the relationship between DE and product characteristics could be determined. Changes in temperature would affect only the thermodynamics of the process whereas changes in airflow rate would affect both the thermodynamics and fluid dynamics of the particles during coating.

3.1.1. Effect of change in inlet air temperature

DE increased at a decreasing rate with increasing temperature (Fig. 2a). At the lowest temperature of 60 °C, the DE was low as the drying air could not remove very efficiently the moisture deposited onto the pellets. As the temperature increased to 70 °C, the air relative humidity was lowered and had greater capacity for moisture uptake by the higher vapor pressure difference. This caused the increase in DE to be fast as there was much moisture

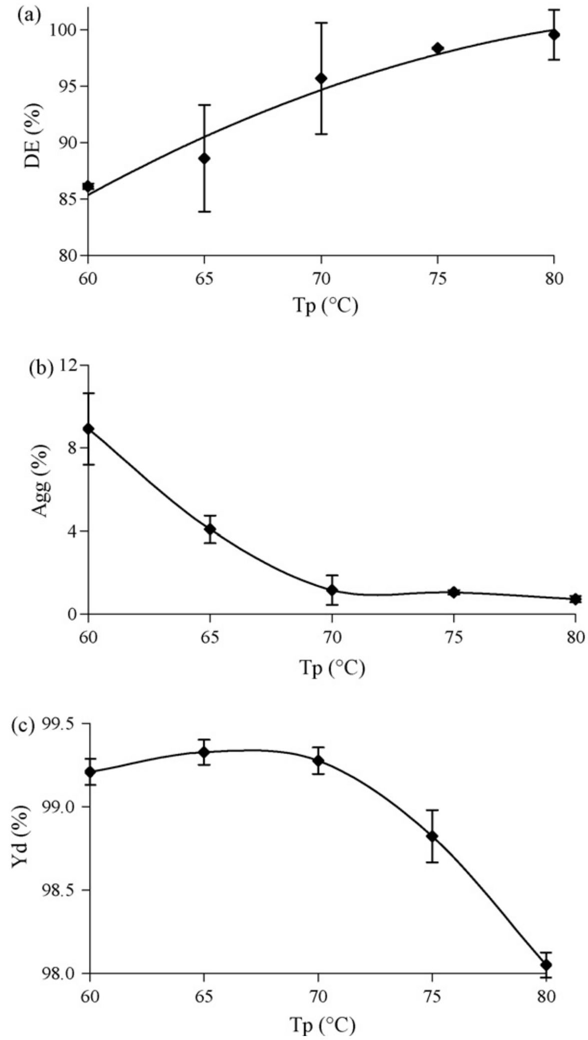

Fig. 2. Influence of inlet air temperature, T_p, on (a) DE, (b) Agg and (c) Yd in precision coating (AF = 80 m^3/h, AI diameter = 20 mm, PG = 18 mm).

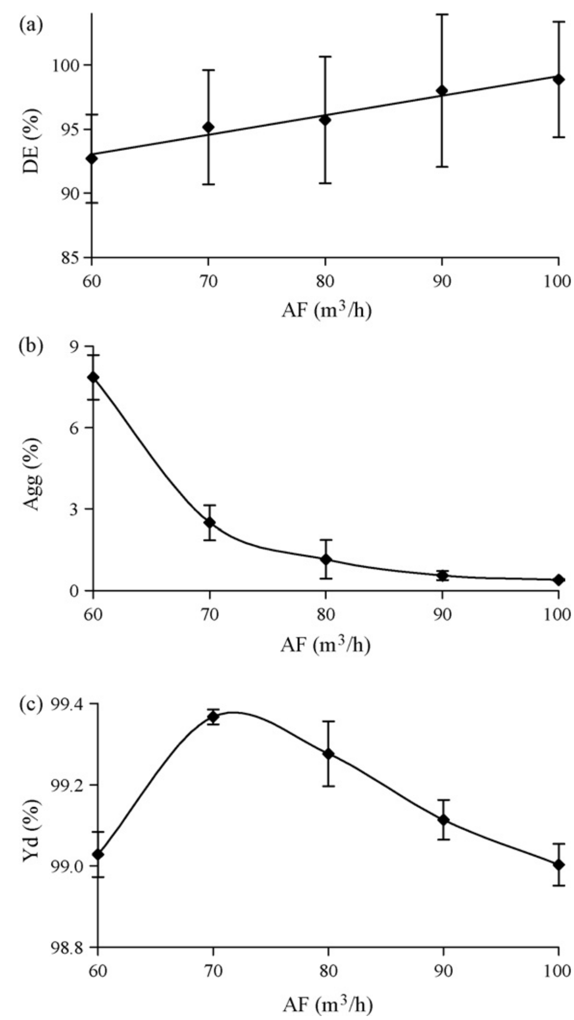

Fig. 3. Influence of airflow rate, AF, on (a) DE, (b) Agg and (c) Yd in precision coating (T_p = 70 °C, AI diameter = 20 mm, PG = 18 mm).

in the product that could be removed. Beyond 70 °C, the DE leveled off close to 100% and agglomeration reached a minimum (Fig. 2b) but the yield started to decrease (Fig. 2c). This indicated that as almost all the moisture was removed beyond the T_p of 70 °C, the excessively dry condition conferred little additional benefit in reducing agglomeration. Moreover, it caused a decrease in Yd due to spray-drying effect or attrition. This suggested that the optimal thermodynamic condition for coating was when DE approached close to 100%, whereby the drying condition was just sufficient to remove all the moisture introduced into the system.

3.1.2. Effect of change in airflow rate

When the airflow rate was increased, the DE increased from 93% at the AF of 60 m^3/h to 98% at the AF of 90 m^3/h, reaching a high of 99% at the AF of 100 m^3/h (Fig. 3a). The DE came close to 100% beyond the AF of 80 m^3/h, showing that almost all the moisture introduced had been removed under those conditions. Increasing the AF further caused slight reduction in Agg (Fig. 3b) but marked decrease in Yd (Fig. 3c). The trends were similar to those observed when T_p was increased (Fig. 2) and could be attributed to the same reasons.

Although the DE at AF of 60 m^3/h with T_p of 70 °C (Fig. 3a) was higher than that at AF of 80 m^3/h with T_p of 60 °C (Fig. 2a), the degree of agglomeration was similar at about 8.5% (Figs. 2b and 3b). This showed that in addition to DE, the pellet movement was also important in influencing Agg. The lower airflow rate caused inadequate fluidization of the pellets resulting in the high Agg observed. There was also a slight reduction in Agg beyond the AF of 80 m^3/h, which could be due to the increased fluidization of the pellets at higher airflow rates.

3.2. Influence of fluid dynamics on drying efficiency, agglomeration and yield

3.2.1. Effect of change in airflow pattern

The DE and particle movement in swirling airflow of precision coating was compared with those in non-swirling airflow of Wurster coating. While comparing both airflow patterns, the

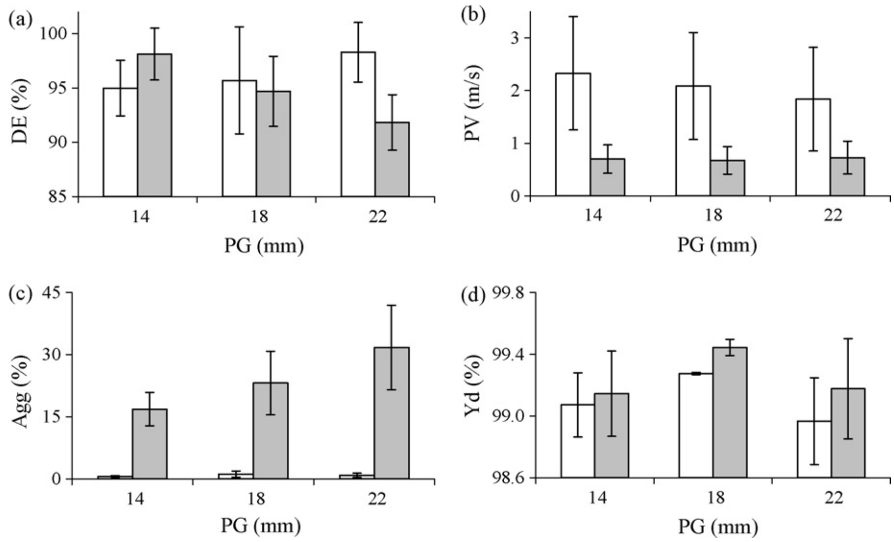

Fig. 4. Influence of partition gap on (a) DE, (b) PV, (c) Agg and (d) Yd in precision coating (clear) and Wurster coating (shaded) (T_p = 70 °C, AF = 80 m^3/h).

impact of the partition gap was also studied as it was found to influence the fluid dynamics of particles moving up the partition column in these coaters. Increasing partition gap can result in more particles moving in from the periphery product bed into the partition column but the pressure differential may be lowered, resulting in sluggish pellet movement into and up the partition column (Chan et al., 2006).

Differences in airflow pattern affected the DE to different extents (Fig. 4a). DE in precision coating remained high (95–98%) over the partition gaps studied, showing that almost all the moisture introduced into the system was removed by the drying air. This led to the low Agg of pellets obtained. However, the DE in Wurster coating decreased from 98 to 92% and the Agg of pellets increased with increasing partition gaps (Fig. 4c). Despite the similar DE values in both airflow patterns at PG of 14 and 18 mm, the Agg values of pellets were much lower in precision coating than in Wurster coating (Fig. 4c). This indicated that it was not just insufficient drying condition that had contributed to Agg, rather other factors relating to pellet movement in Wurster coating had also contributed to the formation of agglomerates.

High speed photography showed that pellets were in closer proximity in Wurster coating as compared to precision coating, thus increasing the liability for collisions and formation of liquid bridges between pellets undergoing coating (Fig. 5). This was also observed in previous studies (Chan et al., 2006; Heng et al., 2006). Pellet movement into the partition column in Wurster coating was found to be primarily due to gravity feed whereas that of precision coating was due to suction pressure or venturi effect (Chan et al., 2006). As the partition gap was increased, the amount of pellets moving into the partition column in Wurster coating increased whereas the amount of pellets entering the partition column in precision coating would be limited by the suction pressure exerted by the inlet air. In addition, the PV in precision coating was about three times higher than that of Wurster coating (Fig. 4b). The faster pellet movement through the spray zone in the partition column would result in less coating material deposited per pellet with each passage through the coating zone and faster drying of the pellets during coating, thus reducing the Agg. The lower PV in Wurster coating also indicated a less turbulent airflow system, whereby the pellets would be moving up the partition column in a more orderly fashion than in precision coating. This would have discouraged the breaking of conjoined pellets with interconnecting bridges, which were earlier formed when the pellets collided and coalesced.

The Yd values were similar for precision coating with PG of 14 and 22 mm, showing that the amounts of spray-drying effect and attrition were similar (Fig. 4d). However, there was a small but marked increase in Yd observed at a partition gap of 18 mm. The same trend was observed for Wurster coating. This suggested that there was an optimal partition gap for pellet flow into the partition column. A very narrow PG would restrict pellet flow into the partition column, leading to scarcity of pellets in the spray zone and loss of spray material to the inner wall of the partition column. On the other hand, a very wide PG would allow a heavy pellet load to enter the partition column, resulting in sluggish material flow and longer transit time through the spray zone. In the latter situation, pellets became wetter and agglomerative problems remained a constant threat.

3.2.2. *Effect of change in accelerator insert diameter*

In precision coating, the AI diameter can be changed to adjust the air velocity within the partition column. A smaller AI diameter would generate higher air velocity, in accordance with the law of conservation of mass. This would increase the pressure differential across the partition gap and impart greater acceleration to particles passing through the spray zone. However, this was not reflected by the similar PV values for the 20 and 24 mm AI diameters ($p > 0.05$) (Fig. 6b). This could be due to the concentration of air movement as a central jet in the partition column

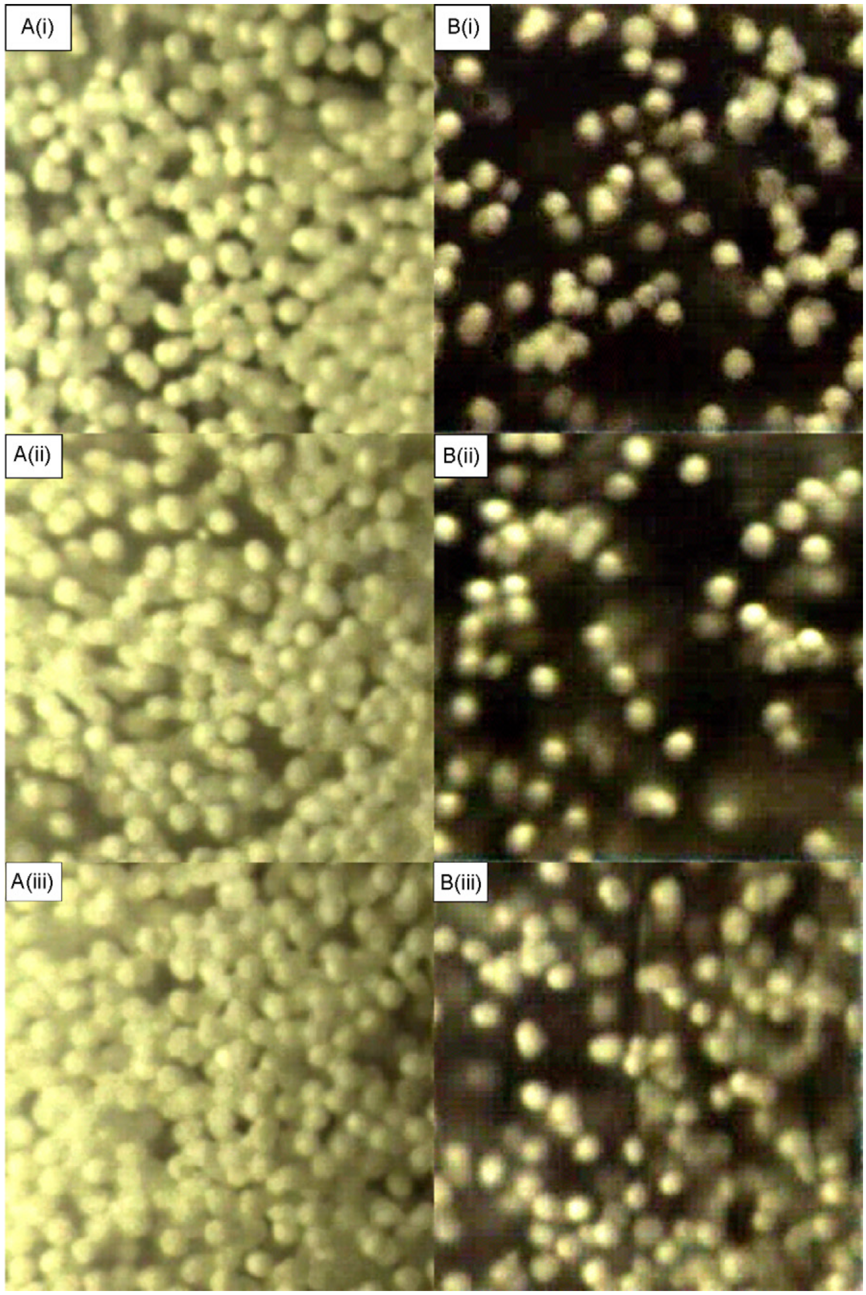

Fig. 5. High speed images of pellet movement in (A) Wurster coating and (B) precision coating at partition gap of (i) 14 mm, (ii) 18 mm and (iii) 22 mm over an area of 10 mm × 10 mm.

with the 20 mm AI diameter such that the particle velocities were higher only in the middle but compromised further out from the center, making the overall PV similar to that of the 24 mm AI diameter. The PV decreased significantly only for the 30 mm AI diameter where the air velocity was generally lower, resulting in a reduction of PV within the partition column. This was substantiated by air velocity measurements at the peripheral and center parts of the partition column (Fig. 7) which showed that air velocity was significantly higher in the center than peripheral of the partition column, and that the smallest AI diameter had the highest air velocity at the center and the lowest air velocity at the peripheral of the partition column ($p < 0.05$).

The largest AI diameter of 30 mm had the lowest DE (Fig. 6a), showing that low PV compromised the drying of the pellets. Despite the similar PV at AI diameters of 20 and 24 mm, the Agg obtained with the 20 mm AI diameter was unexpectedly larger than that of the 24 mm AI diameter (Fig. 6c). For the 20 mm AI diameter, faster moving air concentrated in the center of the partition column left the peripheral of the partition column with much lower air velocity (Fig. 7). This could have compromised the overall particle movement through the partition column, resulting in a greater tendency for agglomeration. Thus, a balance in air velocities within the partition column, as seen in the 24 mm AI diameter, was necessary to ensure opti-

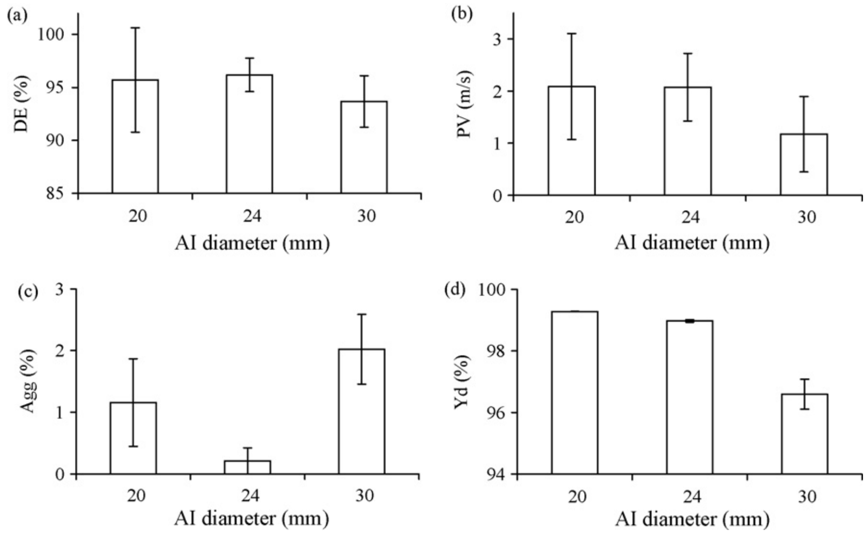

Fig. 6. Influence of accelerator insert (AI) diameter on (a) DE, (b) PV, (c) Agg and (d) Yd in precision coating (T_p = 70 °C, AF = 80 m^3/h, PG = 18 mm).

mal particle movement up the partition column and minimize Agg. This showed that while PV was important in affecting Agg, the pellet trajectories within the partition column also had great impact on Agg. It was visually observed that there were more pellets falling downwards at the peripheral region within the partition column with the use of a larger AI diameter. This phenomenon will be quantified in another study as it is beyond the scope of this paper.

Close pellet proximities with AI diameter of 30 mm also contributed to a higher Agg (Fig. 8). Moreover, it was reported that the mass flow rate of pellets decreased with larger AI diameter (Chan et al., 2006). This indicated that the pellets moved up the partition column more slowly and closely together for larger AI diameters. The slower moving pellets could have received comparatively more coating material while passing through the spray zone and took a longer time to dry. Coupled with the closer proximity of pellets, the conditions favored the formation of liquid bridges between pellets. The slower drying could have led to loss of deposited coating material to the surrounding as the pellets brushed against the walls of the coating chamber and partition column, resulting in a lower Yd (Fig. 6d).

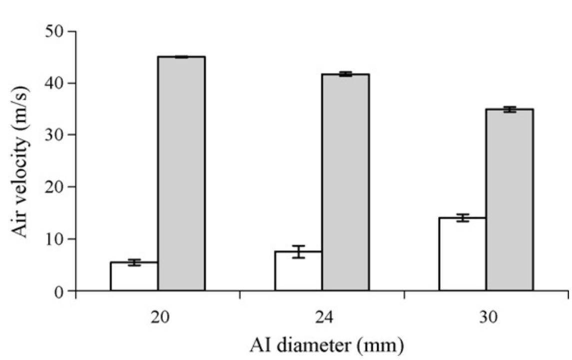

Fig. 7. Influence of accelerator insert (AI) diameter on the air velocities at the peripheral (clear) and center (shaded) positions within the partition column in precision coating (AF = 80 m^3/h, atomizing pressure = 1.5 bar, PG = 18 mm).

3.3. Influence of pellet size on drying efficiency and agglomeration

Airflow rate and partition gap were two of the main process variables in fluid bed coating. However, there are limited reports of their influence on small particle coating. Hence, the following experiments were carried out to determine the suitability of these process conditions for the coating of smaller particles.

Generally, smaller pellets had lower DE and higher Agg than larger pellets (Figs. 9 and 10). This could be attributed to the similar atomizing pressure used for coating both sizes of pellets. The atomizing pressure used could have produced spray droplets that were small enough for coating the larger pellets, minimizing agglomeration but too big for the smaller pellets, encouraging formation of liquid bridges (Hemati et al., 2003). Once coalesced, smaller pellets would become more cohesive and difficult to separate, producing clusters of agglomerates which retained moisture within and further from the surface. Larger pellets, with lower specific surface area, had a lower propensity to agglomerate by nature (Smith and Nienow, 1983).

3.3.1. Effect of change in airflow rate

There was a greater increase in DE with the increase in AF for smaller pellets than for larger pellets (Fig. 9a). Smaller pellets required a higher AF to facilitate the drying process due to the higher degree of over wetting of the product bed. The increase in DE was accompanied by marked reduction in the Agg for both pellet sizes, especially for smaller pellets (Fig. 9b), showing that the DE was a major factor affecting agglomeration of particles during coating. Besides the improvement in DE, the increased movement of pellets with increased AF would help to break up liquid bridges. This probably resulted in the greater reduction

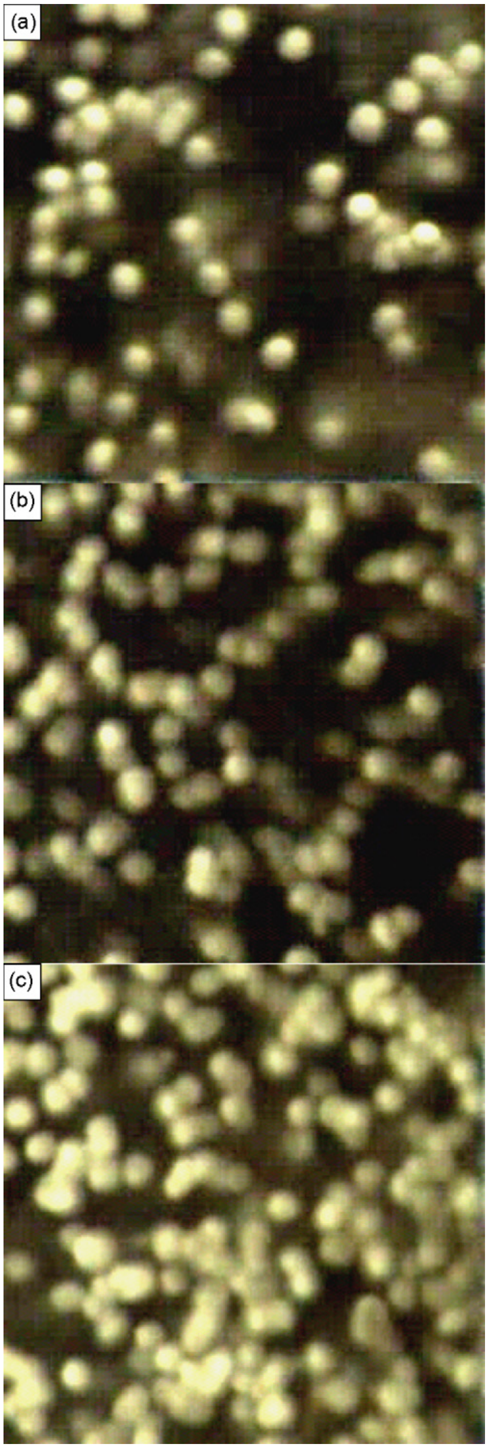

Fig. 8. High speed images of pellet movement in precision coating using accelerator insert (AI) diameters of (a) 20 mm, (b) 24 mm and (c) 30 mm over an area of 10 mm × 10 mm.

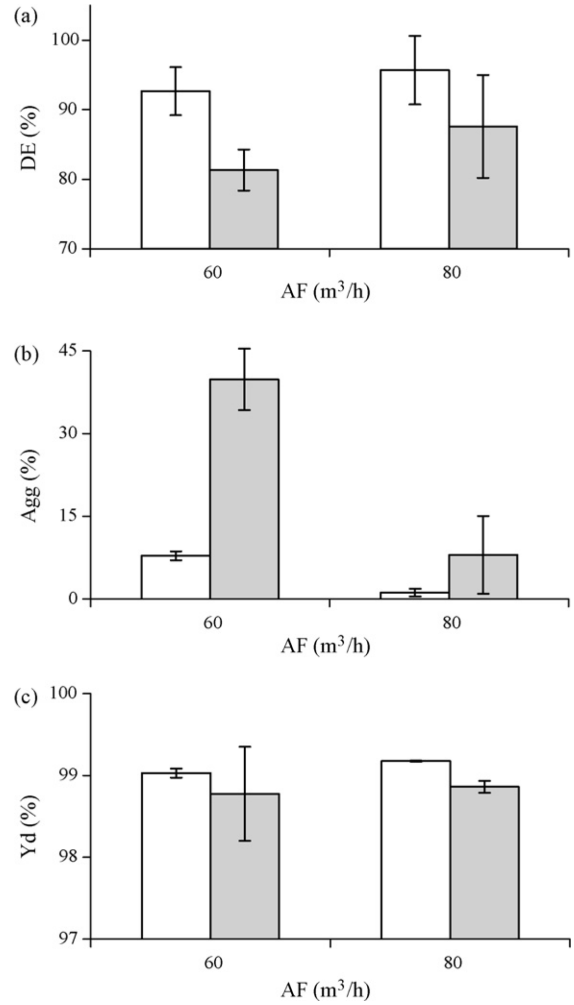

Fig. 9. Influence of AF, on (a) DE, (b) Agg and (c) Yd on precision coating for pellets of 500–600 μm (clear) and 355–425 μm (shaded) (T_p = 70 °C, AI diameter = 20 mm, PG = 18 mm).

in Agg of smaller pellets than larger pellets, which would have fewer agglomerates to break up.

The Yd of smaller pellets was generally lower than that of larger pellets, being more apparent at the higher AF (Fig. 9c). This showed that the smaller pellets were relatively more difficult to be coated when subjected to faster moving particles brought about by higher AF conditions. Thus, depending on the importance of Agg or Yd on the final product, AF should be carefully controlled in the coating of smaller pellets.

3.3.2. *Effect of change in partition gap*

There was a slight increase in DE with increasing PG for larger pellets, however, it did not cause much change to the Agg. For the smaller pellets, DE decreased and Agg increased substantially at a larger partition gap (Fig. 10a and b). The higher pressure differential generated by the smaller PG was favorable in lowering Agg especially for smaller pellets. This was probably due to the more effective suction of smaller pellets into and up the partition column at a smaller PG.

There was overall significant increase in the Yd with partition gap for the larger pellets (Fig. 10c). A smaller PG served to restrict the amount of pellets that can enter the partition column. While the smaller pellets were not affected by the smaller PG due to their size, the larger pellets were more restricted. This might have caused the pellet mass flow into the partition column to be scarce and the lower pellet proximity resulted in the loss of coating material to the surrounding partition column wall. Hence, a small partition gap may be used to achieve a lower Agg

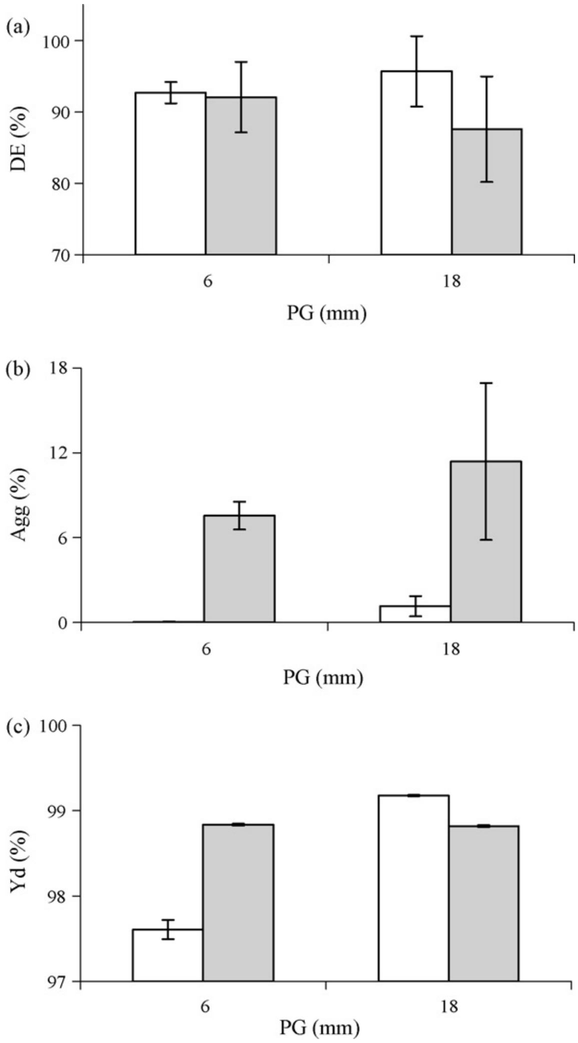

Fig. 10. Influence of PG, on (a) DE, (b) Agg and (c) Yd in precision coating for pellets of sizes 500–600 μm (clear) and 355–425 μm (shaded) ($T_p = 70\,°C$, AI diameter = 20 mm, AF = 80 m^3/h).

but it is important to balance pellet mass flow into the partition column.

4. Conclusion

Agg was found to be minimized at a DE of ∼100%, whereby all the moisture introduced was removed by the drying air. Once DE approached 100%, further drying decreased the Yd due to spray-drying effect and attrition. Low DE was often associated with high Agg, however, a high DE did not always result in low Agg. This was attributed to the influence of particle movement on the agglomeration tendency of the pellets. In some process conditions, despite being able to remove all the moisture that was introduced, significant agglomeration could still occur if the particle movement was not ideal. In the comparison of airflow patterns and air velocities, it was observed that PV, pellet proximity and pellet trajectories influenced the tendency of agglomeration.

Smaller pellets were harder to dry and required a higher AF condition to improve the DE and reduce the Agg. However, the higher AF caused the Yd to be compromised due to the greater attrition of smaller pellets. A smaller PG provided greater suction of pellets and was favorable in reducing Agg especially for smaller pellets. Smaller PG restricted the mass flow of larger pellets into the partition column and resulted in loss of material to the surrounding. Hence, careful considerations must be made to ensure adequate drying, low Agg and acceptable Yd depending on the size of pellets being coated.

References

Chan, L.W., Tang, E.S.K., Heng, P.W.S., 2006. Comparative study of the fluid dynamics of bottom spray fluid bed coaters. AAPS Pharm. Sci. Technol. 7, Article 37.

Cole, G.C., 1995. Introduction and overview of pharmaceutical coating. In: Cole, G.C. (Ed.), Pharmaceutical Coating Technology. Taylor & Francis, London, pp. 1–5.

Dechesne, J.P., Delattre, L., 1986. A new enteric tablet of acetylsalicylic acid. II. Biopharmaceutical aspects. Int. J. Pharm. 34, 259–262.

Hemati, M., Cherif, R., Saleh, K., Pont, V., 2003. Fluidized bed coating and granulation: influence of process-related variables and physicochemical properties on the growth kinetics. Powder Technol. 130, 18–34.

Heng, P.W.S., Chan, L.W., Tang, E.S.K., 2006. Use of swirling airflow to enhance coating performance of bottom spray fluid bed coaters. Int. J. Pharm. 327, 26–35.

Johansson, B., Nicklasson, F., Alderborn, G., 1998. Effect of pellet size on degree of deformation and densification during compression and on compactability of microcrystalline cellulose pellets. Int. J. Pharm. 163, 35–48.

Jono, K., Ichikawa, H., Miyamoto, M., Fukumori, Y., 2000. A review of particulate design for pharmaceutical powders and their production by spouted bed coating. Powder Technol. 113, 269–277.

Maronga, S.J., Wnukowski, P., 1998. The use of humidity and temperature profiles in optimizing the size of fluidized bed in a coating process. Chem. Eng. Process. 37, 423–432.

Ozbey, M., Soylemez, M.S., 2005. Effect of swirling flow on fluidized bed drying of wheat grains. Energy Convers. Manage. 46, 1495–1512.

Ronsse, F., Pieters, J.G., Dewettinck, K., 2007. Combined population balance and thermodynamic modeling of the batch top-spray fluidised bed coating process. Part I. Model development and validation. J. Food Eng. 78, 296–307.

Shallcross, D.C., 1997. Psychrometric charts. In: Shallcross, D.C. (Ed.), Handbook of Psychrometric Charts: Humidity Diagrams for Engineers. Blackie Academic & Professional, London, pp. 44–45.

Smith, P.G., Nienow, A.W., 1983. Particle growth mechanisms in fluidized bed granulation. I. The effect of process variables. Chem. Eng. Sci. 38, 1223–1231.

Sugito, K., Ogata, H., Goto, H., Noguchi, M., Kogure, T., Takano, M., Maruyama, Y., Sasaki, Y., 1990. Gastrointestinal transit of non-disintegrating solid formulations in humans. Int. J. Pharm. 60, 89–97.

Tang, E.S.K., Chan, L.W., Heng, P.W.S., 2005. Coating of multiparticulates for sustained release. Am. J. Drug Deliv. 3, 17–28.

Walter, K., 1998. Apparatus for coating solid particles. US Patent 5,718,764.

Wurster, D.E., 1953. Method of applying coating onto edible tablets or the like. US Patent 2,648,609.

Yilmaz, M., Comakli, O., Yapici, S., Sara, N., 2003. Heat transfer and friction characteristics in decaying swirl flow generated by different radial guide vane swirl generators. Energy Convers. Manage. 44, 283–300.