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Note

The effect of suction during die fill on a rotary tablet press

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Abstract

Die fill on a rotary tablet press involves complex powder flow phenomena. Conventional techniques for measuring flowability do not normally provide information that is directly relevant to the design of powder feed systems or to the selection of press parameters for the die filling process. Sinka et al. [I.C. Sinka, L.C.R. Schneider, A.C.F. Cocks, Measurement of the flow properties of powders with special reference to die fill, in: International Journal of Pharmaceutics 280 (1–2) (2004) 27–38] used an experimental shoe–die system to characterise the flow behaviour of pharmaceutical powders. A rigorous data analysis procedure was developed by Schneider et al. [L.C.R. Schneider, I.C. Sinka, A.C.F. Cocks, Characterisation of the flow behaviour of pharmaceutical powders using a model die–shoe filling system, in: Powder Technology (in press)] to evaluate the experimental results, however, when scaling the results to a rotary tablet press, the die fill efficiency was underpredicted by a factor of approximately 2, because the experimental system did not capture major features of the rotary press flow process. The suction effect, whereby the lower punch is moved downwards while the top of the die is exposed to powder in the feed system, is a key element of the process. In this note we describe the development of a model shoe–die system that allows the effect of suction to be investigated. The results demonstrate the improvement offered by suction and illustrate how a fundamental understanding of die fill phenomena could assist the selection of process parameters to maximise the operational speed of a rotary press.

Keywords: Powder flow; Die fill; Suction fill; Tablet press

1. Introduction

Rotary presses are used for high volume production, of the order of 100,000–500,000 tablets per hour. The central component of a rotary press is a round die table with a number of tooling stations, which consist of upper punch–die–lower punch assemblies. The operating cycle of a rotary tablet press is illustrated in Fig. 1, which is based in broad terms on the layout of a Fette 1000 rotary press (Fette GMBH, Schwarzenbeck, Germany). As the die table (1) rotates, as indicated in Fig. 1a, each tooling station passes successively through the die fill mechanism (4), compression rollers (6 and 7) and ejection cam mechanism (8). The characteristics of die fill are described below.

Single station presses employ sliding shoe delivery systems. The dominant driving force for this configuration is gravity. On rotary presses (Fig. 1), the die fill system consists of a mass flow hopper connected to a feed frame. The feed frame consists of a gravity hopper and can include motor-driven powder transfer mechanisms depending on size of the press and flow properties of the material that is being compressed. For a typical production press the feed frame contains number of paddle wheels as illustrated in Fig. 1a. The paddle wheels (3) and (5) are in the immediate vicinity of the die table and are referred to as feeding and metering wheels, respectively. As described elsewhere in more detail [3] the die fill mechanisms in addition to gravity fill also include:

- force feed: the feeding wheel has profiled paddles which stir and transfer the powder towards the die opening

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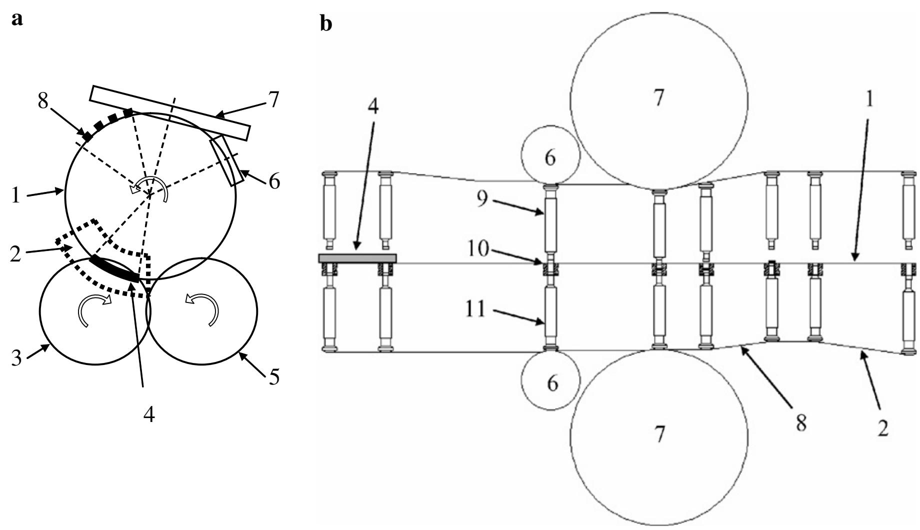

Fig. 1. Rotary press production cycle. (a) Top view, (b) unfolded view. 1, Die table; 2, fill cam; 3, feed wheel; 4, die fill area; 5, metering wheel; 6, pre-compression roller; 7, main compression roller; 8, ejection cam; 9, upper punch; 10, die; 11, lower punch (after Sinka and Cocks [2]).

- suction fill: the lower punch is moved downwards using a fill cam to create the die cavity while the top of the die is exposed to powder
- weight control mechanism: after the die is filled, the lower punch is moved upwards and part of the powder is ejected
- for larger rotary presses, such as that illustrated in Fig. 1a, weight uniformity is assisted further by the presence of a second paddle wheel (metering wheel)
- additional effects include: centrifugal forces and vibration of the system during the operation of the press.

2. Materials and methods

The contributing factors can be investigated experimentally using a model die–shoe system [4] illustrated in Fig. 2. The shoe is filled with powder and is translated over the die at a given velocity, which can be prescribed in the range 10–1000 mm s^{-1}. The mass of powder deposited in the die is dependent on the shoe velocity. The fill ratio is defined as the ratio between the mass of powder deposited in the die by the travelling shoe and the powder mass in the full die. At low shoe velocities, the die is completely filled. As the shoe velocity is increased, the fill ratio decreases. The maximum velocity that still achieves complete die fill is termed the critical velocity. The critical velocity was proposed as a measure of flowability by Wu et al. [4].

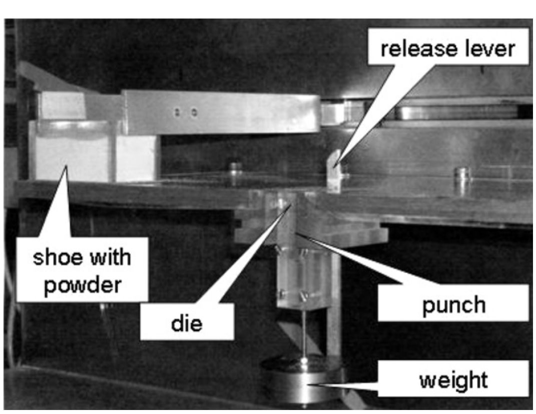

Fig. 2. Model shoe–die filling system showing the suction device, which consists of a punch located into the die, connected to a weight which is released by the travelling shoe acting upon a release lever.

The flow behaviour of seven pharmaceutical excipients and powder formulations has been characterized using the model die–shoe system [1], which allowed evaluation of the flow behaviour under the effect of gravity. Dimensional analysis was employed to provide a framework for interpretation of the experimental results and to guide the extrapolation procedures to other die and shoe geometries [1]. When scaling the experimental results from model die–shoe system (using gravity feed only) to the rotary tablet press it was predicted that the die would be less than half full at conventional operating speeds. This result suggests that other factors (i.e. suction effects) may play an important role.

Following the methodology described by Schneider et al. [1] experiments have been carried out using microcrystalline cellulose Avicel PH102 (manufactured by FMC Biopolymer) as a model material. Furthermore, the experimental system was modified to allow withdrawal of the lower punch while the shoe was above the die (as indicated in Fig. 2), thus simulating the suction effect. In the system of Fig. 2 the top of the punch is initially flush with the top of the die. It is held in place by a lever. As the shoe moves across the die opening the lever is released, allowing the punch to drop under its own weight. In this set-up there is no control on the velocity of the punch, which accelerates under gravity to its lower position, but the set-up provides

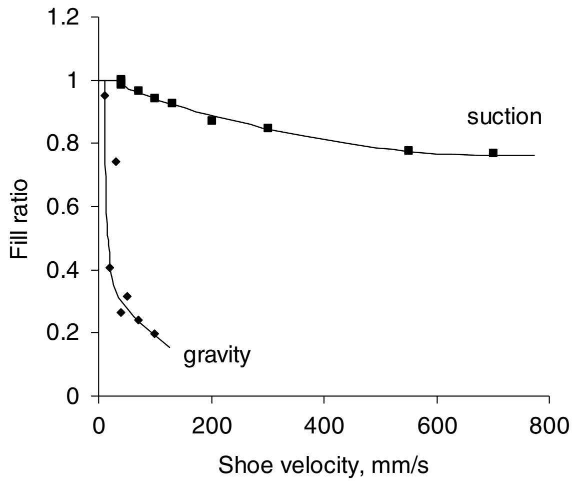

Fig. 3. Fill ratio and critical velocity for microcrystalline cellulose for gravity feed and suction feed.

a consistent set of test conditions. The shoe dimensions employed in this study are $65 \times 30 \times 35$ mm. The die opening is 10×10 mm and the height is 20 mm.

3. Results and discussion

The fill ratio for a placebo powder mixture is presented as a function of shoe velocity in Fig. 3 for gravity feed only and under combined gravity and suction. The critical velocity is determined using the data points that correspond to incomplete die fill. The results indicate that suction filling improves the critical velocity by a factor of approximately 2.5 (from approximately 25 mm s^{-1} to approximately 80 mm s^{-1}). Use of this higher velocity gives a more accurate prediction of the die fill behaviour of the powder in the rotary press.

Fig. 3 also illustrates that under suction filling the fill ratio drops less steeply at velocities in excess of the critical velocity and over 80% of the die is filled at the highest shoe velocities used in the experiment. This observation can be employed to aid the design of the metering process to maximize the operational speed of the press. These initial studies illustrate how a fundamental understanding of the flow process can be used to guide the design of the manufacturing process.

Use of a transparent die and shoe (Fig. 2) allows visual observation of the details of the die fill process using high-speed video. For gravity feed, the punch is set to the maximum fill position prior to filling as presented in Fig. 4a. The incoming powder interacts with the air present in the die which permeates through the powder bed in the shoe above and through the clearances between punch and die. The air pressure build-up reduces the net flow rate of powder into the die and creates turbulence which can cause segregation (both within the die and in the powder bed above).

Suction fill entails creating the die cavity as the lower punch is withdrawn at the same time as the powder is fed into the die as illustrated in Fig. 4b. In effect, during suction fill a partial vacuum is created under the powder in the shoe. Thus air is not trapped to oppose the flow of the powder into the die. Also, air initially in the powder pores wants to expand as the vacuum is created below and this further aids the flow process. Under these conditions the powder is fed into the die as a continuous column, which also reduces the opportunity for segregation.

The repeatability of the measurements presented in Fig. 3 is influenced by the details of the die fill process, which depends on the characteristics of the powder, geometry of die and shoe and the process parameters. Intermittent flow (Schneider et al., unpublished results) results in larger variations, while a more uniform fill process, such

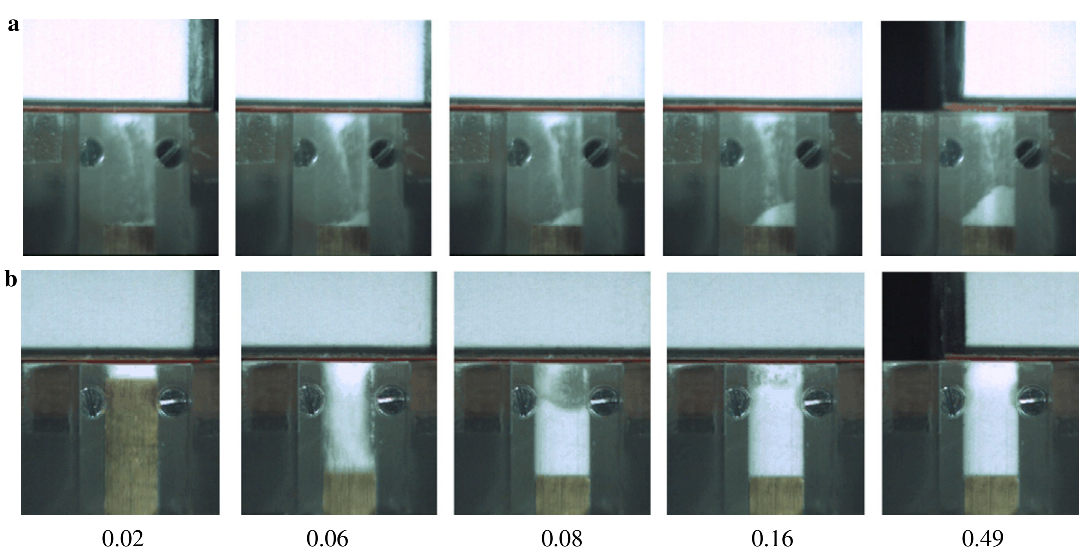

Fig. 4. Comparison between gravity and suction fill, using a mixture of placebo powder. The shoe velocity is 100 mm/s. The labels indicate time in seconds, starting from the instant when suction fill is initiated. (a) Gravity fill (top row), (b) suction fill (bottom row).

as using the suction mechanism, results in more consistent results.

In conclusion, the flow behaviour of powders into constrained open cavities is strongly influenced by air pressure build-up. Suction is an important component of the die fill process on production presses, which influences the detailed flow behaviour as well as the mass flow rate. Die fill uniformity is often a limiting factor for setting the operating speed on a rotary press. The above results suggest that an understanding of the details of the die fill process could contribute to improvements in the design of the powder feed systems and in the selection of process parameters that maximise the productivity of a rotary press. Moreover, it can be assumed that if the lower punch is withdrawn at a higher velocity (i.e. by increasing the turret speed) then the higher vacuum created could increase the suction feed efficiency. This remark could contribute to explaining an empirical observation that in certain situations it is possible to overcome problems related to die fill uniformity by increasing the turret speed. However, more detailed studies are necessary to control and scale the kinematics of suction feed and to include the force feed effect in order to extrapolate the results from the experimental shoe–die system to tablet presses.

References

[1] L.C.R. Schneider, I.C. Sinka, A.C.F. Cocks, Characterisation of the flow behaviour of pharmaceutical powders using a model die–shoe filling system, Powder Technology, in press.

[2] I.C. Sinka, A.C.F. Cocks, in: P.R. Brewin, O. Coube, P. Doremus, J.H. Tweed (Eds.), Modelling Die Compaction in the Pharmaceutical Industry, Springer, in press.

[3] I.C. Sinka, L.C.R. Schneider, A.C.F. Cocks, Measurement of the flow properties of powders with special reference to die fill, International Journal of Pharmaceutics 280 (1–2) (2004) 27–38.

[4] C.Y. Wu, L. Dihoru, A.C.F. Cocks, The flow of powder into simple and stepped dies, Powder Technology 134 (2003) 24–39.