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Differences between eccentric and rotary tablet machines in the evaluation of powder densification behaviour

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Abstract

Differences in the dynamics of powder densification between eccentric and rotary machine were pointed out by compressing at different compression pressures microcrystalline cellulose, lactose monohydrate and dicalcium phosphate dihydrate and recovering the corresponding stress/strain data in both machines equipped to monitor punches displacement and compression forces. Heckel plots were then obtained from these stress/strain data.

Curves obtained in the rotary machine possess a narrower zone of linearity for the calculation of P_Y and D_A. The effect of the different compression mechanism of the rotary machine on the shape of the Heckel plot is more noticeable in a non-deforming material such as dicalcium phosphate. The effect of the longer dwell time of the rotary machine on the porosity reduction occurring after the maximum pressure has been reached, is more noticeable in a ductile material such as microcrystalline cellulose.

Heckel parameters obtained in the rotary press are in some cases different from those recovered in the eccentric machine because of the longer dwell time, machine deflection and punch tilting occurring in the rotary machine, although theoretically they could better describe the material densification in a high speed production rotary machine.

Keywords: Compression; Compaction; Tableting; Mechanical properties; Rotary tablet machine; Densification; Heckel; Stress; Strain

1. Introduction

Tablets are the most common pharmaceutical dosage form but the compression of powdered or granular material into a cohesive mass is a complex and irreversible dynamic process, in contrast to its apparent simplicity.

Mechanically, the process consists of imposing a progressive strain on the powder confining it to a certain final volume and porosity.

The dimensional constraints imposed by the punches and die are then removed and the compact is allowed to relax.

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The compacted material exerts a certain stress against the punches and die during this process in response to the imposed strain.

Generally, a solid material can be characterised from a rheological point of view using a creep test (Tsardaka and Rees, 1989; Celik and Aulton, 1996) and dynamic mechanical analysis (Radebaugh et al., 1989).

Besides, useful information concerning the fundamental structure of tablets can be drawn from compression stress/strain data and researchers have accomplished many efforts in order to develop methods of evaluation based on these data. In fact, in this way, the formation of the compact and its subsequent behaviour under stress, inside the die of a tablet machine, can be monitored.

For instance, among these methods, force/displacement curves allowing the evaluation of the energy expenditure during powder compaction firstly proposed by Nelson et al. (1955) and the plot of minus logarithm of tablet porosity versus compression pressure (Heckel, 1961a,b) have been widely applied.

In particular, this last technique of analysis has recently become the most used due to the fact that it gives a good level of information about the dynamics of powder densification in the die.

The Heckel equation is:

$$\ln\left[\frac{1}{1-D}\right] = KP + A$$

where D is the relative density and $(1 - D)$ denotes the pore fraction, P the applied pressure, K the slope of the straight linear portion of the plot and the reciprocal of K is the mean yield pressure (P_Y), and A is the intercept of the prolonged linear portion of the plot with the Y axis and is the sum of two densification terms:

$$A = \ln\left[\frac{1}{1-D_0}\right] + B$$

where D_0 is the initial relative density and B is the densification due to the slippage and rearrangement of primary and fragmented particles.

So, the relative density at point A is $D_A = 1 - e^{-A}$ and the increase of relative density due to slippage and rearrangement is $D_B = D_A - D_0$.

The use of this method requires the measurement of the force as it varies during the punch penetration inside the die.

Compaction simulator represents a powerful mean to collect these data, particularly when material characterisation is needed, since it can reproduce different compression kinetics (Rees et al., 1972; Celik and Marshall, 1989; Muller and Augsburger, 1994).

Otherwise, single station eccentric presses are still used to acquire the stress/strain data. In fact, in this type of machine, only the upper punch penetrates the die to compress the material whilst the position of the lower punch does not change (except deflection) during the tablet formation. For this reason, eccentric presses can be easily instrumented to measure the axial forces exerted by both punches and the distance moved by the upper punch.

Anyway, an eccentric press cannot reproduce the compression conditions occurring on a rotary multi-station press in which the lower and upper punches both move and penetrate inside the die.

Moreover, there can be considerable differences in relative punch speed penetration between the low velocities encountered on eccentric presses and the higher velocities possible on the rotary presses. Since compact formation is based on time-dependent visco-elastic properties, the speed of the process can have marked effects on compactibility and tendencies to lamination, capping and picking.

It is easy to instrument a rotary press to measure changes in punch force during a compression cycle, but the measurement of the punch displacement poses some formidable problems due to the difficulties of retrieving signals from the moving punches and turrets.

Punch displacement of rotary tablet machines was calculated by equation (Rippie and Danielson, 1981; Charlton and Newton, 1984) as a function of time, from the profile of the punch head, machine dimensions, turret velocity and punch position relative to the compression roller. Unfortunately, in this way, punches and machine deflections cannot be taken into account.

Upper and lower punches of a rotary press were then instrumented to measure both force and displacement (Walter and Augsburger, 1986). Two linear variable displacement transducers were mounted in the empty punch and die sockets adjacent to the station holding the instrumented upper and lower punches. These transducers were linked to the punches through rigid brass linkages. Data were collected from the rotating turret through an eight-channel mercury swivel system. Dis-