

The influence of initial packing on the compression of powders

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The influence of the initial packing density on the compression properties of lactose and sodium chloride has been studied. Differences in initial packing density are eliminated for both materials at relatively low pressures. The results have been analysed by the equations of Kawakita (1956), Heckel (1961), and Cooper & Eaton (1962). The constants derived from the Cooper & Eaton equation are dependent on the choice of low pressure data. The Kawakita constants are influenced by the initial packing of the powder. The Heckel treatment uses data at pressures above the point where the initial packing exerts an influence. Hence the constants are independent of the initial packing. If comparisons are to be made between processing treatments or mixtures which change the initial packing of the powder, the Heckel equation would appear to offer the most valid approach.

The determination and interpretation of pressure-density relationships in the compaction of pharmaceutical powders has received much attention (Hersey et al 1972; York 1978; Armstrong & Morton 1979). Emphasis has been placed on using the data to determine the mechanisms of powder compaction, and to derive physical constants which can be used as a basis for comparison between materials. The matter is, however, open to debate (Rue & Rees 1978; York 1979).

Of the many equations used to describe the compaction process, those of Kawakita (1956), Heckel (1961) and Cooper & Eaton (1962) have been applied to the compaction of pharmaceutical powders:

Kawakita:

$$\frac{V_0 - V}{V_0} = \frac{abP}{1 + bP}$$

V_0 is the initial powder volume, V is the volume at pressure P , and a and b are constants.

Heckel:

$$\ln \frac{V}{V - V_\infty} = kP + A$$

where V_∞ is the true volume of the solid and K and A are constants:

Cooper & Eaton:

$$\frac{V_0 - V}{V_0 - V_\infty} = a_1 e^{-K_1/P} + a_2 e^{-K_2/P}$$

where a_1 , a_2 , k_1 and k_2 are constants.

None of these equations was derived from consideration of a physical model of compaction. They are essentially curve fitting formulae (Cooper &

Eaton in deriving their equation considered compaction to be a two stage process but then assumed that the porosity would diminish exponentially with pressure for both processes).

The equations have achieved popularity because they have been shown to fit compaction data over a wide range of pressures, especially in the regions of interest where a coherent compact is being formed. In addition, the constants in the equations have been related to material properties. Heckel correlated the slope of the compaction curves K , with the yield strength of the material being compressed. This was extended by Hersey & Rees (1970) who correlated K with the mean yield pressure. The constant, b , in the Kawakita equation has been related to the plasticity of the powder (James 1972). The constants a_1 and a_2 in the Cooper & Eaton equation represent the fractional volume compaction $(V_0 - V)/(V_0 - V_\infty)$ achieved by each stage of the two stage process and K_1 and K_2 the pressures at which each process is occurring with maximal effect.

Thus, treating compaction data by the approaches outlined above should provide useful comparative data. York (1979), however, has pointed out that certain experimental variables will influence the results obtained from these treatments. These are the history of the powder, mode of filling, rate of compaction, contact time, punch and die dimensions, the state and type of lubrication and whether the dimensions of the compact are measured 'at pressure' or after ejection. Hence careful control of experimental conditions must be adopted if quantitative estimations are to be made. The values obtained will only be applicable to the particular set of experimental conditions chosen.

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While most of the experimental variables listed above can be easily controlled, the initial volume or bulk density of the material in the die cannot. This is especially so if comparison between materials, mixtures, or processing treatments is required. To obtain useful comparative data in cases where the treatment causes a change in initial bulk density, the equations used to treat the data must be insensitive to this parameter. Of the three equations described, those of Cooper & Eaton and Kawakita require a knowledge of the initial powder volume to treat the data, whereas the Heckel equation does not. We have examined the influence of the initial bulk density of a material on its compaction characteristics.

MATERIALS AND METHODS

Materials

Lactose and sodium chloride were chosen to represent materials which compact by different mechanisms. Lactose B.P. was from a single batch obtained from Unigate Food Ltd., and sodium chloride (Analar grade) was a single batch from BDH Ltd. The 45–75 μm size fractions of the materials were obtained by sieving using an Alpine Air Jet Sieve (Alpine Process Technology, Runcorn). Compression was carried out using an Instron Physical Testing Instrument at a crosshead speed of 0.1 cm min^{-1} in the manner described by Fell & Newton (1970). A large die (1.905 cm, diam, 2.5 cm long, equipped with flat faced punches) was employed to obtain more accurate measurements of powder bed movement. Excess powder was poured into the die and then scraped level with the top of the die. To obtain a greater initial bulk density, the die was tapped before the powder was scraped level with the top. The compacts were weighed after ejection and only results from compacts within 2.5% of the mean weight were used. The upper punch was brought down until it was level with the top of the die, and the crosshead and chart recorder started simultaneously. Readings of powder bed height were taken both at pressure and after ejection. (Compacts were stored for 24 h over silica gel before measurement). Allowance was made for deflection of the instrument.

RESULTS AND DISCUSSION

The Instron Physical Testing Instrument allows accurate and reproducible location of the upper punch on the surface of the powder bed and a complete record of force and powder bed movement can be obtained. Plots of compact relative density (compact density/true density of solid) against pressure are shown in Figs 1 and 2. Because of the need to have a

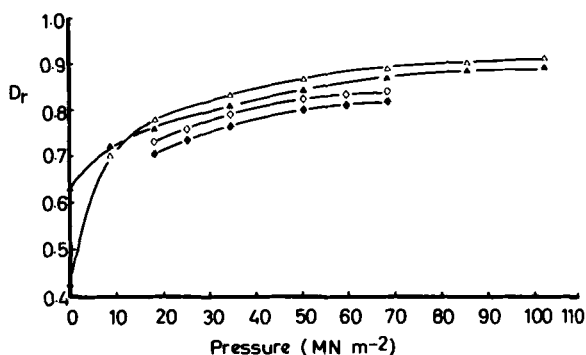


FIG. 1. The relation between compact relative density and compression pressure for lactose. Δ = loose fill 'at pressure'. \diamond = loose fill ejected. \blacklozenge = tight fill 'at pressure'. \blacklozenge = tight fill ejected.

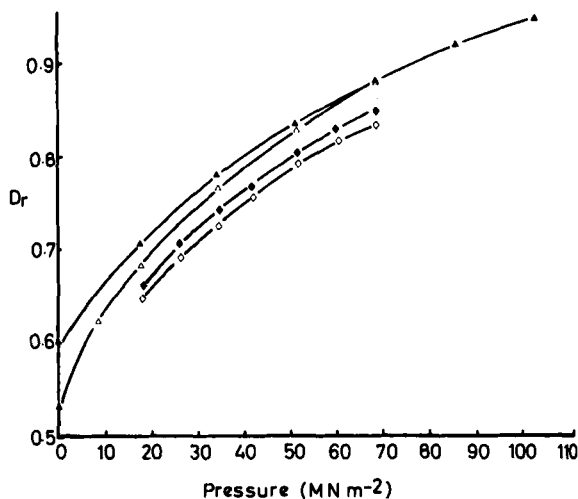


FIG. 2. The relation between compact relative density and compression for sodium chloride. Key as in Fig. 1.

coherent compact for measurement purposes, results for the ejected compacts can be obtained only at higher pressures. For lactose, differences in the initial densities are largely eliminated at pressures above 9 MNm^{-2} although compacts prepared from the low initial bulk density fill have consistently higher relative densities at pressures above 18 MNm^{-2} . For sodium chloride, the differences in relative density remain at higher pressures than for lactose. When the density differences are largely eliminated 'at pressure', the compacts, on ejection and storage, expand to give rise to differences in relative densities. This suggests there are structural differences, in sodium chloride tablets prepared from the two initial fill densities.

Lactose particles are more irregular in shape than sodium chloride particles, allowing greater differences

in initial bulk density to be achieved, and greater possibilities for rearrangement of particles under low loads. In addition, lactose particles fracture under load (Hersey & Rees 1970) and this will aid in the elimination of initial bulk density differences under relatively low pressures. Sodium chloride has fewer possibilities for rearrangement and consolidates by plastic flow rather than fracture (Hersey & Rees 1970) and hence the initial bulk density differences are retained until higher pressures.

The above results were subjected to analysis by the Cooper & Eaton, Heckel and Kawakita equations. The Kawakita equation is rearranged to give:

$$\frac{P}{C} = \frac{1}{ab} + \frac{P}{a} \left(\text{where } C = \frac{V_0 - V}{V_0} \right)$$

Plots of P/C against P allow the constants to be calculated graphically. Typical Kawakita plots are shown in Fig 3, these exhibit deviations from linearity at low pressures in common with the findings of

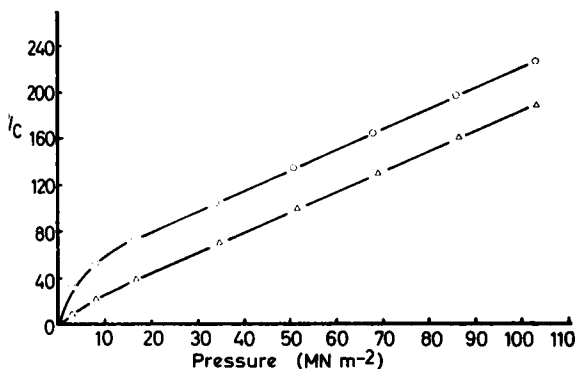


FIG. 3. Typical Kawakita plots for sodium chloride and lactose. ○ = sodium chloride, loose fill 'at pressure'. △ = lactose.

Hersey et al (1972) and Kawakita & Lüdde (1970). Data at pressures of 18 MNm⁻² and above were used to determine the constants given in Table 1 by linear regression analysis. The constant a is equal to the

initial porosity of the powder bed (from examination of the original equation, Kawakita & Lüdde (1970) and b is a compression coefficient related to the plasticity of the powder (James 1972). The constant, a, shows good agreement with the measured initial porosities for lactose, but not for sodium chloride. Except for the results from ejected compacts of sodium chloride, there is not a good agreement between the constants, b, from the two different initial filling conditions. Combining the constants as suggested by Brackpool (1970) i.e. $\beta = b(1-a)/a$, gives overall, a slightly better agreement.

The constants from the Cooper & Eaton equation are derived from plots of 1/p against $(V_0 - V)/V_0 - V_\infty$. On the assumption that at low pressures, only the first compaction mechanism is taking place, extrapolation of the plots at low pressures to 1/p = 0 established a value for a₁. Similar extrapolation at the highest pressures gives a₁ + a₂. With these constants determined, k₁ + k₂ are calculated by fitting the data at the lowest and highest pressures respectively (Cooper & Eaton 1962). The problem with this

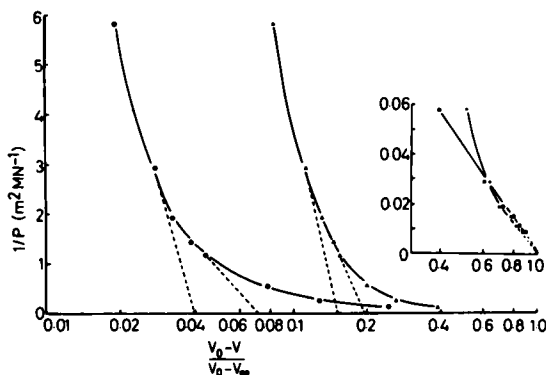


FIG. 4. The relation between $(V_0 - V)/(V_0 - V_\infty)$ and $1/p$ for lactose and sodium chloride used to find a_1 and $a_1 + a_2$ in the Cooper & Eaton equation. Note the variation in the value of a_1 depending on the pressure chosen. The inset shows higher pressure values extrapolated to determine $a_1 + a_2$. ● = sodium chloride, tight fill 'at pressure'. ▲ = lactose tight fill 'at pressure'.

Table 1. The constants determined from the Kawakita equation for lactose and sodium chloride.

| Measurement | Initial fill | Lactose | | | | Sodium chloride | | | |
|-------------|--------------|---------|---------------------|-------|---------------------|-----------------|---------------------|-------|---------------------|
| | | a | b × 10 ³ | E | β × 10 ³ | a | b × 10 ³ | E | β × 10 ³ |
| At pressure | Tight | 0.372 | 1.96 | 0.383 | 3.31 | 0.510 | 0.906 | 0.406 | 0.870 |
| | Loose | 0.558 | 7.29 | 0.575 | 5.77 | 0.565 | 1.35 | 0.480 | 1.04 |
| Ejected | Tight | 0.371 | 2.74 | 0.383 | 4.65 | 0.513 | 1.30 | 0.406 | 1.23 |
| | Loose | 0.498 | 4.67 | 0.575 | 4.71 | 0.621 | 1.37 | 0.480 | 0.836 |

E = the initial porosity of the powder bed.

approach can be seen by examining Fig. 4, where the data are plotted in the appropriate manner. A wide variation in the value of a_1 can be found, depending on the pressures chosen; in normal compaction experiments, data at the very low pressures used in the current work are not determined. For lactose, by choice of a suitable a_1 value, and the determination of the other constants from this, good agreement can be achieved between a theoretical curve generated from the equation and the experimental data. No agreement could be achieved for sodium chloride.

Typical Heckel plots (Fig. 5) show the commonly observed deviations from linearity at low pressures

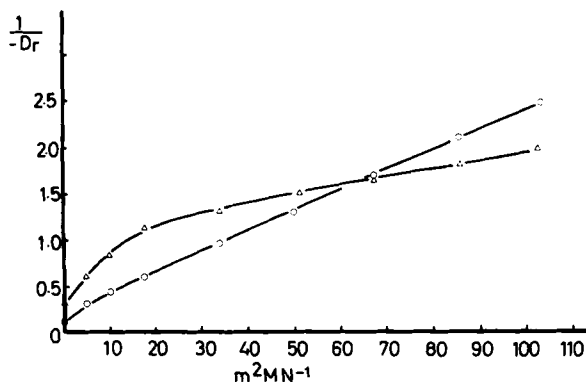


Fig. 5. Typical Heckel plots for sodium chloride and lactose. Key as in Fig. 3.

(Hersey et al 1972; York 1978). Data above 18MNm^{-2} were used to determine the constants given in Table 2 by linear regression analysis. As can

Table 2. The constants determined from the Heckel equations for lactose and sodium chloride.

| Measurement | Initial fill | Lactose | | Sodium chloride | |
|-------------|--------------|---------|--|-----------------|--|
| | | A | $\frac{K}{m^2 \text{MN}^{-1}} \times 10^3$ | A | $\frac{K}{m^2 \text{MN}^{-1}} \times 10^3$ |
| At pressure | Loose | 1.35 | 1.12 | 0.73 | 2.13 |
| | Tight | 1.30 | 1.08 | 0.85 | 1.99 |
| Ejected | Loose | 1.15 | 0.950 | 0.77 | 1.59 |
| | Tight | 1.10 | 0.947 | 0.86 | 1.48 |

be seen, the values obtained are in reasonable agreement showing an independence from initial filling conditions.

Both the Cooper & Eaton and Kawakita equations require a knowledge of the initial volume of the powder bed. Compaction experiments must therefore be designed to allow this measurement, as estimates may be in error. In addition, Cooper & Eaton's equation requires data at very low pressures to make an estimate of a_1 . As has been shown, large

differences in this estimate will be obtained depending on the pressures chosen. Comparisons based on this constant must therefore be viewed with caution.

The Heckel constants are derived from data at pressures where initial relative density differences have been largely eliminated. Hence the values of the constants show good agreement between the two initial filling conditions. As these data are taken from a region where a coherent compact is forming, the equation would appear to be the most useful for producing comparative data, providing the precautions mentioned in the introduction are observed. An example is shown in Table 3, where the Heckel

Table 3. The constants determined from the Heckel equation for a mixture of 60% lactose, 40% sodium chloride.

| Measurement | Initial fill | 60% Lactose A | 40% Sodium chloride $m\text{N m}^{-2} \times 10^3$ |
|-------------|--------------|------------------|---|
| At pressure | Loose | 0.99 | 1.54 |
| | Tight | 1.02 | 1.40 |
| Ejected | Loose | 0.97 | 1.05 |
| | Tight | 0.98 | 1.09 |

constants for a mixture of lactose and sodium chloride are given. The mixture inevitably has an initial bulk density different from those of the pure materials, but as the Heckel constants are independent of the initial bulk densities for the pure materials and the mixtures, comparison is justified and the influence of one component on the other may be examined in terms of the Heckel constants.

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