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The effect of distribution of magnesium stearate on the penetration of a tablet by water

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Magnesium carbonate powder and granules were compressed and the tablets characterized by their permeability to air and penetration by liquids. To the same materials, magnesium stearate was added, its distribution being varied by varying its concentration, the size of the base material and the method of mixing. The inhibition of penetration by liquids is roughly proportional to the concentration of magnesium stearate and very susceptible to the method of mixing. The influence of granule size on its distribution was seen mainly as a change in the uniformity of penetration.

Magnesium stearate is a boundary lubricant widely used in tabletting and, like most boundary lubricants, it is strongly hydrophobic. If its concentration in a tablet is sufficiently high, penetration of water into the tablet is prevented. In lower concentrations, its less extreme effects are lengthening of tablet disintegration time (Strickland, Nelson & others, 1956; Kwan, Swart & Mattocks, 1957) and decrease in the rate of dissolution of tablet constituents (Levy & Gumtow, 1963). The mechanism by which this is achieved is complex. Contamination of surfaces by magnesium stearate will modify the mechanisms of bonding during compression and, therefore, the break-up of a tablet in water. Changes in the shape and size distribution of the capillaries which conduct water into the tablet may result from the volumetric contribution of a powder like magnesium stearate which compacts with ease, or the reduction of interparticulate friction which it produces. It is probable, however, that the major mechanism lies in the inhibition of penetration due to the high contact angle of magnesium stearate with water.

The force driving a liquid into a tablet is derived from the pressure difference, ΔP existing across the curved menisci of the liquid entering the capillaries of the tablet. Carman (1941) gives this pressure difference as:

$$\Delta P = \frac{\gamma \cos \theta}{m}$$

where γ is the surface tension of the penetrating liquid and θ is the contact angle between the penetrating liquid and the capillary surface. m is the ratio of the cross-sectional area of the capillary and its perimeter. This expression of dimensions takes account of irregularity in capillary shape. If θ is less than 90°, ΔP is positive and the liquid moves through the capillary. The contact angle of water on magnesium stearate is greater than 90° so that water will not enter a tablet composed of this material. An intermediate effect will be found when magnesium stearate is mixed and compressed with a powder which is freely wetted by water. Capillaries with

surfaces composed of some proportion of magnesium stearate will not then transmit water and the proportion of capillaries so affected will depend upon the distribution of magnesium stearate through the tablet matrix. For given samples of lubricant and powder base, the three major factors which will affect this property are: (i) concentration of magnesium stearate; (ii) the processes of tablet manufacture; (iii) the intensity of mixing operations.

The effect of concentration is relatively straightforward. Higher proportions of lubricant yield an increase in the non-wetting internal surface and the number of capillaries not contributing to the transport of water.

Two aspects of the manufacture process are important. The first is the stage at which the lubricant is added. In tabletting by precompression, some lubricant is added before 'slugging' and some after. In tabletting by direct compression, all constituents are mixed as fine powders. In wet granulation and compression, all the lubricant is added to the aggregated powder. At any level of concentration these processes give a different distribution of lubricant. This may be further modified by the size of the base material. For example, differences in granule size are encountered for reasons of tablet dimensions and press coating and magnesium stearate added after granulation will be discontinuously distributed, the thickness of the regions of lubricant and the scale of discontinuity being determined by the size of the granules.

Finally, mixing will play an important part in the distribution of a lubricant. The problems of dispersing a small proportion of a highly cohesive powder through a mass which is probably of quite different particle size are obvious enough. When a limit is imposed on the mixing energy which can be expended in order to avoid the break-up of granules, the dangers of maldistribution become severe and a gross variation in the aqueous penetration of tablets subsequently prepared becomes possible.

The assessment of the role played by magnesium stearate within the tablet will be complicated if conditions at the die wall are allowed to vary. These conditions, which affect the pattern of forces within the tablet and therefore its pore structure and penetration, are themselves influenced by the concentration of magnesium stearate. A further difficulty is that the method of granulation affects pore structure and liquid penetration (Ganderton & Selkirk, 1969). In the work described below, tablets prepared from magnesium carbonate were characterized by their permeability to air and penetration by liquids. These properties were compared with those of tablets containing magnesium stearate compressed under conditions which eliminated variation in activity at the die wall.

EXPERIMENTAL

Granulation

Magnesium carbonate (5 kg) was granulated by massing with 2·7 litres of 10% w/v aqueous dextrose solution in a ribbon blender and forcing the mix through a coarse screen. The wet granules were dried, rescreened and the fractions 8–16 mesh, 16–22 mesh and 30–44 mesh collected. In addition, a sample of fines passing through a 200 mesh screen was taken. The great bulk of the material lay in the 16–22 mesh fraction and to this, quantities of magnesium stearate, which had been freed from lumps, were added to give a number of granulations containing between 0% and 5% lubricant. The components were mixed by first subdividing each component and

then blending the fractions. The fractions were then mixed by tumbling. To the other granule sizes, magnesium stearate was added to give a concentration of 1%. The initial proportionation of the components was omitted and the components mixed by tumbling.

Other materials were prepared as follows: Samples of 16–22 mesh granules containing $\frac{1}{2}$ or 1% magnesium stearate added before massing. A sample of the original magnesium carbonate powder containing 1% magnesium stearate mixed in by tumbling. A sample of the original magnesium carbonate powder containing 1% magnesium stearate mixed in by shearing in a pestle and mortar.

Compression

Granules or powder (2·5 g) were placed in a die 1·92 cm in diameter which was closed at the lower end by a spigot which penetrated 0·95 cm into the die. The punch was inserted and the assembly pressed between the platens of a small hydraulic press. The studied pressure range of 10–200 MNm^{-2} was measured in a manner described by Shotton & Ganderton (1960) with strain gauges affixed to the shank of the punch.

Before each compression, the wall of the die was liberally coated with stearic acid which was applied as a 2% solution in carbon tetrachloride and allowed to dry.

Die wall conditions were assessed for all materials in a further experiment in which the spigot of the punch assembly was replaced by a lower punch bearing strain gauges. The apparatus was re-assembled with an independent die support and an accurately measured force of about 29 kN applied. The lower punch force was simultaneously measured, the difference between these values giving the force loss at the wall of the die.

Measurement of porosity, permeability and liquid penetration rate

The porosity of a tablet was calculated from its weight and volume after the density of each component had been measured with a density bottle. In this calculation, the volumetric contribution of each component was assumed to be additive.

The air permeability of the tablets was measured, while they were still in the die, with an apparatus similar to that described by Lea & Nurse (1939). The flow of air through the tablet, Q, was measured at a pressure difference of 62 $\pm$ 0·7 kNm^{-2}. The permeability coefficient, B_0, was calculated from the relation

$$B_0 = \frac{2QL\eta P_1}{A\,(P_1^2 - P_2^2)}$$

where A and L are the area and thickness of the tablet and η is the viscosity of the air. P_1 and P_2 are the upstream and downstream pressures.

The rate at which liquid entered a tablet by capillarity was measured by the method of Ganderton & Selkirk (1969). It consisted of moving the tablet to a position in which its lower surface was flush with the die. This was placed in a cup which formed one arm of a liquid-filled U-tube and the rate of uptake measured as the withdrawal of liquid from the other arm. Water and cyclohexane were used in the tests and all experiments were made on tablets compressed to a porosity of 33·4 $\pm$ 0·1%.

RESULTS

Measurement of applied and transmitted forces at a moderate level of compaction showed that the ratio of the lower punch force to the upper punch force for all materials fell within the range 0·96–0·99. Details of these measurements for the compression of 16–22 mesh granules, to which up to 5% magnesium stearate was added, are given in Table 1.

Table 1. *Effect of concentration of magnesium stearate on the force lost at the die wall during compression of 16–22 mesh granules of magnesium carbonate*

Magnesium stearate %	Upper punch force kN	Lower punch force kN	Force loss kN
0	29·3	28·9	0·4
0·5	29·8	29·1	0·7
1·0	30·1	29·2	0·9
2·0	29·5	29·2	0·3
5·0	29·3	29·1	0·2

In Fig. 1, the permeability coefficient of tablets containing no lubricant is shown as a function of porosity. Similar data are presented in Fig. 2 for tablets prepared from granules in which the concentration and distribution of magnesium stearate was varied.

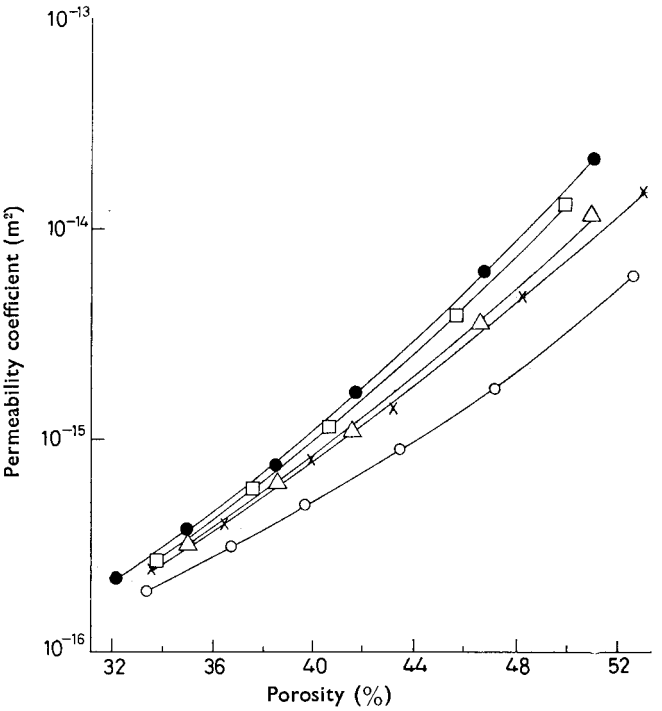

FIG. 1. The permeability of tablets containing no magnesium stearate. ● Compressed granules: 8–16 sieve, □ 16–22 sieve, △ 30–44 sieve, × –200 sieve, ○ Compressed ungranulated powder.

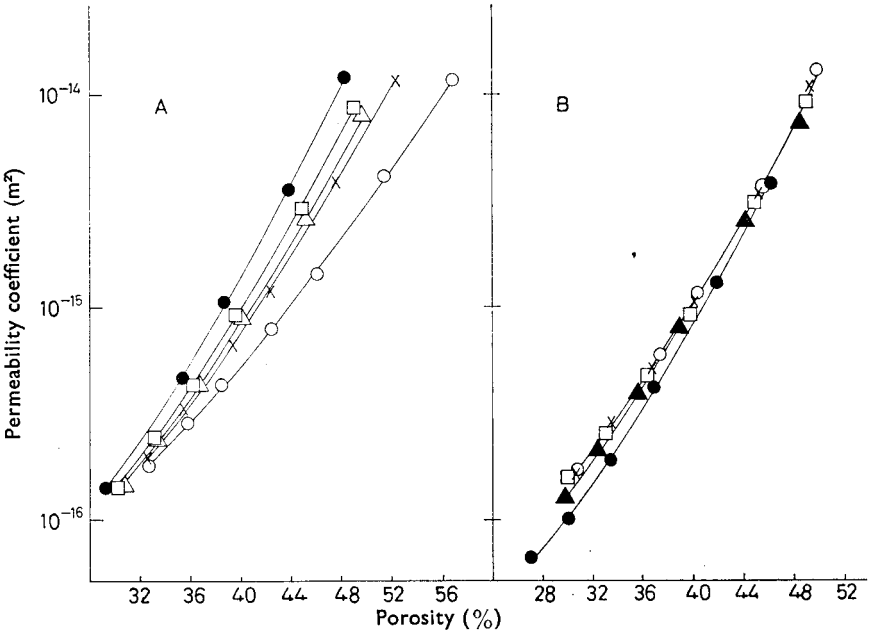

FIG. 2. The permeability of tablets containing magnesium stearate. A. Containing 1% lubricant. ○ Compressed ungranulated powder. Compressed granules: ● 8–16 sieve, □ 16–22 sieve, △ 30–44 sieve, × −200 sieve. B. Compressed 8–16 granules. Magnesium stearate: ○ 0%, × ½%, □ 1%, ▲ 2%, ● 5%.

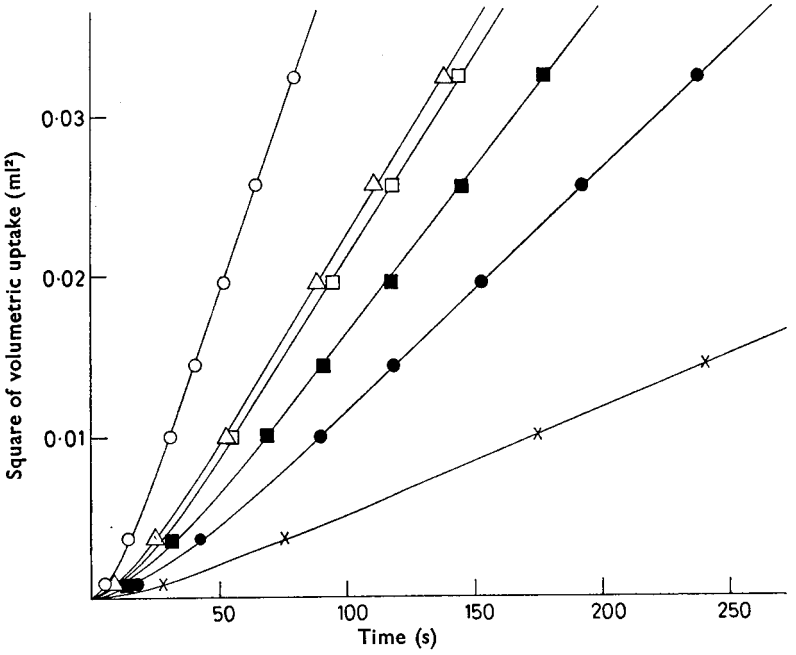

FIG. 3. Penetration of tablets by liquids. ○ Compressed ungranulated powder by water. Compressed 16–22 granules by water: △ no lubricant, ■ 1% lubricant, ● 2% lubricant, × 5% lubricant, □ Compressed 16–22 granules containing 1% lubricant by cyclohexane.

The general form of the liquid penetration tests is presented in Fig. 3. Data are plotted as the square of the volume taken up against the time. Details of these tests are given in Tables 2–4.

Fig. 4 describes the penetration of water into tablets into which magnesium stearate was incorporated by different methods.

Table 2. *Penetration of tablets by cyclohexane (figures are the mean of 4 results)*

Material compressed	Uptake time for 0·1 ml (s)	
	No magnesium stearate	1% magnesium stearate*
8–16 mesh granules	56·5 ± 3	58 ± 7·5
16–22 mesh granules	51·5 ± 3·5	55 ± 4
30–44 mesh granules	59 ± 2	54 ± 6·5
−200 mesh granules	52·5 ± 4·5	51·5 ± 4·5
Original powder	78 ± 6	77 ± 9

* Added after granulation by tumbling.

Table 3. *Effect of granule size on the penetration of a tablet by water*

Material compressed	Uptake time of 0·1 ml (s)					
	No magnesium stearate			1% magnesium stearate*		
	Mean (8 results)	Standard deviation	Coefficient of variance %	Mean (8 results)	Standard deviation	Coefficient of variance %
8–16 mesh granules	67	6·5	9·7	99	25·0	25·1
16–22 mesh granules	55·5	4·0	7·2	70	15·0	21·4
30–44 mesh granules	47	1·7	3·6	62	4·7	7·6
−200 mesh granules	33	1·4	4·2	44·5	4·0	9·0
Original powder	30·5	1·0	3·3	51·5	2·7	5·2

* Added after granulation by tumbling.

Table 4. *Effect of magnesium stearate concentration on the penetration of water into tablets prepared from 16–22 mesh granules*

Concentration of magnesium stearate* (%)	Uptake time for 0·1 ml (mean of eight results) (s)	Standard deviation (s)	Coefficient of variance (%)
0	55·5	3·8	6·9
0·5	68·5	6·7	9·8
1	80	7·6	9·5
2	94	8·7	9·2
5	186	15·4	8·3

* Added after granulation by subdivision of components, blending and tumbling.

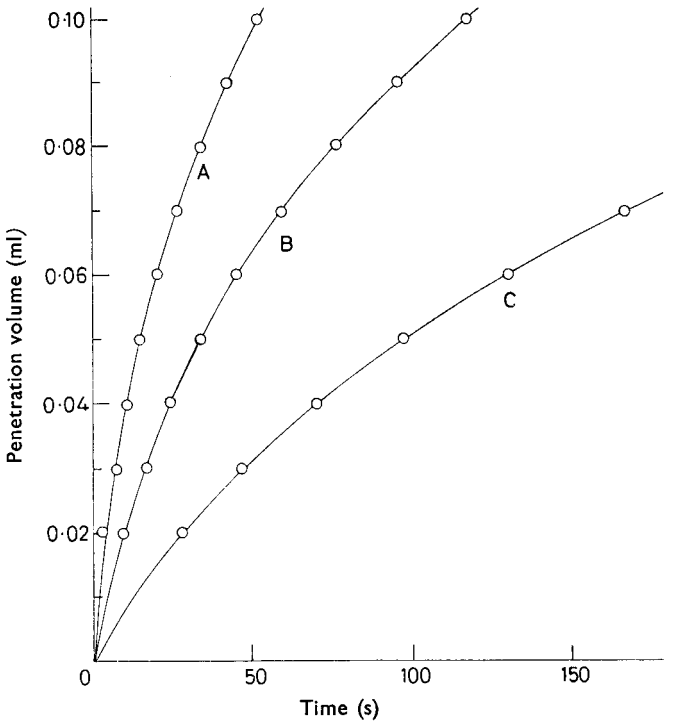

FIG. 4. The effect of method of mixing on the penetration of tablets by water. Magnesium stearate A, 1% tumbler mixed; B, 1% shear mixed; C, ½% wet mixed.

DISCUSSION

Air permeability and liquid penetration tests reveal different aspects of the addition of excipients to a tablet. Changes in air permeability must be ascribed solely to changes in pore volume and its distribution within the tablet. Whilst these geometric effects influence liquid penetration, this test is also susceptible to any change in the wetting of the tablet. Thus, if the additive increases the contact angle, the forces promoting penetration will be decreased and the rate will fall. If on the other hand the contact angle is unchanged, changes in penetration will be similar to those found by air permeation because the pore network transporting fluid is the same.

Tablets containing no lubricant

Fig. 1 shows that decrease in granule size decreases the permeability of tablets compressed to a given porosity. The effect is not large and it diminishes as the tablets become denser. All granule systems, however, were markedly more permeable than tablets prepared from the ungranulated powder.

In the absence of detailed knowledge of the pore size distribution, no conclusive statement can be made on the nature of these permeability changes. However, since the work is a comparative study based on a single powder, it is reasonable to assume that the pore structure of tablets prepared from the original powder is more uniform than that of compressed granular materials and that, in the latter, a coarse pore network originating from the spaces between the granules is increasingly sustained as the granule size increases. A high permeability results because such a network is capable of transporting a disproportionately large amount of fluid.

Similarly, the more uniform structure of tablets prepared from the original powder is more slowly penetrated by cyclohexane than a structure of granular origin. This test did not, however, reveal any effect of granule size on liquid penetration. Differences in structure to be inferred from permeability are small and it is presumed that their effect on liquid penetration is masked by the lower precision of the test.

The pattern of aqueous penetration given in Table 3 is quite different. The rate at which water enters the tablet increases as the size of the granules used decreases. It is fastest in the compressed ungranulated powder. This reversal of the behaviour expected from the permeability studies can only be explained by a change in the structure of the tablet brought about by the penetrating liquid.

The equation given in the introduction evaluates the potential ability of a capillary to draw liquid through its length. This potential increases as the capillary becomes finer but, since the same capillary must transport the liquid, the higher potential is more than offset by increased viscous resistance (Washburn, 1921). The rate of penetration, therefore, falls, which explains the low penetration rate of cyclohexane into fine-structured and relatively impermeable tablets prepared from the ungranulated powder. The high capillary potential of this structure would, however, be realized if the passage of liquid immediately opened the structure, thus reducing the viscous resistance of the wetted portion of the tablet. The coarser structure of more permeable tablets prepared from larger granules has a smaller potential for drawing liquid into a tablet. An opening of the wetted portion of these tablets to the same extent as in tablets prepared from fine powder or granules, would result in a lower penetration rate. By such a mechanism, the order of aqueous penetration rates would be the reverse of permeability.

With the materials compressed here, there are at least two mechanisms by which the wetted structure might be opened. The first is the dissolution of the soluble fraction of the tablet, namely dextrose, which constitutes about 7% by volume of the total solids. The second is a softening of the tablet, probably by the action of a liquid of high dielectric constant on a structure united mainly by secondary bonds. Softening would permit the dissipation of stresses in the tablet by structural rearrangement. Both effects will be present but the fast penetration of magnesium carbonate tablets containing no dextrose suggests that the latter is more important.

The results of the penetration test given in Fig. 3 indicates a linear relation between the square of the volume taken up and the time. This relation results from the balance of the constant capillary forces promoting penetration, and the opposing viscous forces: the latter increase as the depth of penetration increases. Some deviation occurs in the early stages of penetration, the rate being slower than expected. A possible explanation is the existence of a region of the tablet adjacent to the punch which is atypically dense in structure.

Studies of tablets containing magnesium stearate

A die wall previously coated with stearic acid is effective in maintaining almost constant die wall conditions even with a varying concentration of magnesium stearate in the powder being compressed. This conclusion can be drawn from the small variation in die wall losses presented in Table 1. In this study, therefore, die wall friction can be eliminated as a variable influencing the structure of tablets. Under these conditions, the addition of magnesium stearate has little effect on the permeability of tablets. The coincidence of data presented in Figs 1 and 2A shows that the change

in pore structure as the material is compressed is unaffected by the presence, in conventional quantities, of a lubricant. Such an effect might have been expected from the reduction of interparticulate friction and the facilitation of shear failure. When, as shown in Fig. 2B, the concentration is increased, the permeability is reduced, but the effect is significant only at low porosity when the volumetric contribution of the lubricant in relation to the available pore volume is large. Table 2 confirms the insignificant geometric contribution of conventional quantities of magnesium stearate in terms of the penetration of cyclohexane. This liquid freely wets the lubricant so that large effects due to a change in contact angle were not expected.

Wetting effects must therefore be dominant in the large depression of the aqueous penetration rate which occurs when the concentration of magnesium stearate is increased. As shown in Table 4, the increase in penetration time is roughly proportional to the concentration, suggesting a proportional increase in the internal surface of the tablet composed of magnesium stearate and in the number of capillaries unable to conduct water.

It is argued earlier that the size of granules will influence the distribution of a given amount of magnesium stearate throughout a tablet. Examination of Table 3 reveals no clear effect of this variable on the mean rate of penetration. The effect on the uniformity of penetration is, however, most marked. All tablets containing lubricant showed greater variation than the corresponding unlubricated tablets. Deviations in the tablets containing lubricant increased sharply with the coarser granules, the coefficient of variance reaching over 25% with tablets prepared from 8–16 mesh granules. With the smaller overall surface area presented by such granules, even distribution of an additive will be more difficult to achieve. Maldistribution will be locked into the tablet on compression to give a large variation in aqueous penetration from one tablet to another. These variations were least in tablets prepared from the ungranulated powder, the material closest in form to the additive.

There is much evidence to show that the degree of mixing affects the penetration of tablets by water. A comparison of tablets prepared from 16–22 mesh granules to which 1% magnesium stearate was added, can be made from the experimental series given in Tables 3 and 4. Because a lower concentration of lubricant was used in the experiments in Table 4 a more rigorous mixing procedure than that used in other experiments was adopted. This resulted in a slowing of the penetration. A clearer demonstration is seen in Fig. 4. Curves A and B show the effect of 1% magnesium stearate dispersed by different dry mixing actions on the penetration of the tablets subsequently prepared. The more intimate dispersion produced by the energetic shearing process is reflected in a greater inhibition of penetration. Even this process is mild compared to the dispersive capacity of wet mixing. 1% magnesium stearate subjected to this process by an addition during wet massing completely stopped penetration. At half this concentration, the greatly delayed penetration given in curve C is obtained.

In conclusion, the experimental program showed that concentration of magnesium stearate and the degree of mixing greatly affected penetration of tablets by water and the physical form of the granules or powder influenced uniformity of penetration. These factors, which together control the distribution of lubricant, are determined by the tabletting process adopted and the way it is carried out. Since a formulation may vary in both these respects penetration will vary, and so, to some extent, will the steps of disintegration and dissolution which depend upon it.

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REFERENCES

CARMAN, P. C. (1941). *Soil Sci.*, **52**, 1–14.

GANDERTON, D. & SELKIRK, A. B. (1969). Symposium on *Powders*. Society of Cosmetic Chemists of Great Britain. Dublin, 1969.

KWAN, K. C., SWART, F. O. & MATTOCKS, A. M. (1957). *J. Am. pharm. Ass.* (*Sci. Edn*), **46**, 236–239.

LEA, F. M. & NURSE, R. W. (1939). *J. Soc. chem. Ind.*, **58**, 277–283.

LEVY, G. & GUMTOW, R. H. (1963). *J. pharm. Sci.*, **52**, 1139–1144.

SHOTTON, E. & GANDERTON, D. (1960). *J. Pharm. Pharmac.*, **12**, *Suppl.*, 87*T*–92*T*.

STRICKLAND, W. A., NELSON, E., BUSSE, L. W. & HIGUCHI, T. (1956). *J. Am. pharm. Ass.* (*Sci. Edn*), **45**, 51–55.

WASHBURN, E. L. (1921). *Phys. Rev.*, **17**, 273–283.