

The plasto-elasticity and compressibility of coated powders and the tensile strengths of their tablets

OBI EJIOFOR, S. ESEZOBO AND N. PILPEL*

Chelsea Department of Pharmacy, King's College, Chelsea Campus, University of London, Manresa Road, London SW3 6LX, UK

A study has been made of the effects produced on the tensile strength, brittle fracture index (BFI), 'plasto-elasticity' ratio, ER/PC, and yield pressure ($1/K_H$ derived from Heckel plots) of sodium salicylate and calcium carbonate as a result of coating their particles with increasing amounts of silicones and polysorbates before subjecting them to compression to form tablets. The coatings act as lubricants reducing bond formation due to plastic deformation of particles. They caused a reduction in the tensile strengths and yield pressures of the tablets but increased their BFI values and their ER/PC ratios. Tablets of calcium carbonate tended to cap or laminate when their BFI value was >0.7 and their ER/PC ratio was >7 . Sodium salicylate whose BFI values were all <0.7 produced satisfactory tablets when their ER/PC ratio was <10 but tended to cap or laminate when it was >10 .

It has been shown that the tensile strengths of loosely packed pharmaceutical powder beds are affected by the presence of coatings (York & Pilpel 1973; Pilpel & Hephher 1977; Malamataris & Pilpel 1980) and that the strengths of tablets prepared from them depend on the nature and amount of coating, on the plastic deformation of the particles during compression and on their elastic recovery when the pressure is removed (David & Augsburger 1977; Malamataris & Pilpel 1983; Malamataris et al 1984; Hiestand & Smith 1984).

It is well known that the greater the plasticity of a material the greater the number and strength of bonds formed between its particles (Jones 1977; Hiestand et al 1977; Rees & Rue 1978). Malamataris et al (1984) and Bangudu & Pilpel (1985) have in fact shown that an inverse relationship exists between the tensile strength and the plasto-elasticity (ER/PC) ratio of tablets made from a number of pharmaceutical powders.

It has been suggested (Hiestand et al 1977; Hiestand & Smith 1984) that measurement of the brittle fracture index (BFI) of a powder can be used for determining its plasto-elasticity. When a powder is compressed into a tablet, it normally contains residual stresses. Depending on the nature of the material, Hiestand et al (1977) showed that if the tablet is made with a hole in it, most of the residual stresses are concentrated around the hole. As a result, the tablet without the hole has a higher tensile strength than that with the hole (both being made

with the same materials and under comparable conditions). The BFI is measured by comparing the tensile strength of a tablet that contains a hole (T_o) with that of one that does not (T_s) and is defined by (Hiestand et al 1977)

$$BFI = \frac{T_s - T_o}{2T_o} \quad (1)$$

The BFI is claimed to measure the stress relief that occurs due to plastic flow of the material during compression and its value ranges between 0 and 1. Low values (tending to zero) indicate that the material is plastic while values approaching unity indicate that it is elastic with a tendency to cap or laminate.

In the present work a study has been made of the changes produced in the tensile strength, BFI and ER/PC ratios of sodium salicylate and calcium carbonate tablets, by coating the particles with increasing amounts of polysorbates and silicones. The compression behaviour of the coated materials was also analysed in terms of the equation proposed by Heckel (1961).

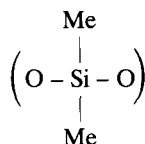
Sodium salicylate was chosen as representative of low density, directly compressible materials and calcium carbonate as representative of high density, poorly compressible materials. Both are insoluble in and apparently unaffected chemically by the coating materials used. The silicones were selected as representative hydrophobic coatings, frequently used as lubricants and the polysorbates (Tweens) as hydrophilic coatings, used as wetting and dispersing agents (Schick & Benson 1967; Kreutler & Davis 1971).

* Correspondence.

MATERIALS AND METHODS

Sodium salicylate (Macarthy's, Romford) and calcium carbonate, precipitated (BDH Ltd, Chadwell Heath), were ballmilled, then classified on a Zig Zag classifier (Alpine Multiplex, W. Germany) to obtain the size range 0–20 μm . The powders were dried in an oven for 48 h at 105 °C. Mean projected particle diameters were determined by optical microscopy, surface areas by nitrogen adsorption and particle densities of the uncoated powders by the immersion method using diethyl ether as the liquid and those of the coated powders with a Beckman air comparison pycnometer Model 930.

Samples were coated with between 0.5 and 5.0 $\times 10^{-6}$ mol g^{-1} of polysorbates (40 and 60) and silicones DC 200/20 and DC 200/50 (Hopkins & Williams) by treating them with ethereal solutions containing the appropriate amounts of coating materials (Pilpel & Hephner 1977; Malamataris & Pilpel 1983). The coated powders were passed through a size 33 μm sieve to break down aggregates and then stored over silica gel at room temperature (20 °C) until ready for testing. The mean molecular weight of each silicone was determined by the viscosity versus \sqrt{n} calibration curve (Midland Silicone Catalogue 1961) where n is the number of siloxane groups.



The value was confirmed by the viscosity method using Staudinger's equation (Weissberger 1949).

$$[\eta] = KM \quad (2)$$

where $[\eta]$ is the reduced viscosity at infinite dilution, K is a constant and M is the molecular weight.

The mean molecular weights of the polysorbates were taken from Martindale (1982). The relevant

physicochemical properties of the powders and coating materials are listed in Table 1, and Appendix 1 shows how the thicknesses of the coatings were calculated.

Preparation and testing of tablets

Samples (600 mg) of the coated powders were compressed into tablets in a hydraulic press (Research & Industrial Instruments Ltd) using 10.5 mm diameter flat faced punches and a die which were lubricated with a 1% w/w dispersion of magnesium stearate in chloroform. Tablets were also made with a hole in their centre by using the punches illustrated in Fig. 1. The tablets were stored over silica gel for 24 h to allow for elastic recovery and their packing fractions were calculated from their weights and dimensions before testing.

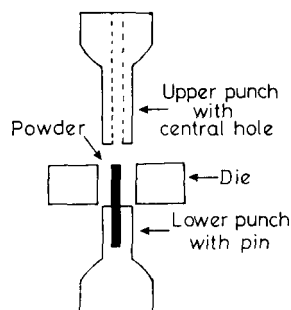


FIG. 1. Punch and die for producing tablets with a central hole.

A Dartec M2501 universal tester (Dartec Ltd) was used to compress 600 mg samples of each of the coated powders using flat faced lower and upper punches—the latter connected to a load cell—and a die of 10.5 mm diameter. The limit ramp was set to 20% and the load rate to 0.667 kNs^{-1} and this resulted in the application of loads up to 20 kN over 30 s as displayed on a scale. The loads were adjusted

Table 1. Some physicochemical properties of the powders and their coatings.

Property	Sodium salicylate	Calcium carbonate	Silicones		Tweens	
			DC200/20	DC200/50	Polysorbate 40	Polysorbate 60
Physical nature	Powder	Powder	Liquid	Liquid	Semi-solid	Semi-solid
Molecular weight	160	100	750	3450	1283.6	1311.7
Solidifying point (°C)	—	—	–60	–50	10	15
Melting point (°C)	—	—	—	—	35	40
Viscosity (cs) at 25 °C	—	—	22 \pm 2	60 \pm 2	—	—
Density g cm^{-3}	1.675	2.687	0.96–0.97	0.96–0.97	1.089–1.092	1.089–1.092
Range of particle size (μm)	0–20	0–20	—	—	—	—
Mean particle diameter (μm)	5.3	9.8	—	—	—	—
Specific surface area ($\text{m}^2 \text{g}^{-1}$)	1.64	1.41	—	—	—	—

to give tablets with a packing fraction of 0.89 for sodium salicylate and 0.76 for calcium carbonate. The loads were maintained for 30 s and released over 30 s. The tablet was ejected over a further period of 30 s so that the whole cycle occupied 2 min. The apparatus was connected to a Bryan X-Y recorder which plotted the load versus the displacement of the upper punch. The length of the horizontal portion of the curve measures the percentage reduction of the applied force with time as a result of plastic compression (Malamataris et al 1984). This is defined as

$$PC = \frac{H_0 - H_L}{H_L} \times 100\% \quad (3)$$

where H_0 and H_L are, respectively, the thicknesses of the tablet after 30 s when first formed and after 60 s at the end of the loading period. PC may vary with the test conditions, e.g. the applied load, the duration and rate of loading and unloading (David & Augsburger 1977), the dimensions of the tablet and the state of the punches and die used.

Similarly, Krycer et al (1982) defined elastic recovery (ER) as

$$ER = \frac{H_0 - H_p}{H_p} \times 100\% \quad (4)$$

where H_p is the thickness of the tablet after ejection from the die. This expression does not take into account the radial expansion of the tablet which occurs during its elastic recovery. Although the ratio ER/PC cannot therefore be considered as an absolute measure of the plasto-elasticity of a powder, provided the experimental conditions are maintained constant it should provide a comparative measure of changes in plasto-elasticity caused by coating the particles with a second species.

The tensile strengths of all the tablets prepared were obtained by diametral compression (Fell & Newton 1970) using a CT40 tester (Engineering Systems, Nottingham) and applying the equation

$$T = \frac{2P}{\pi Dt} \quad (5)$$

where T is the tensile strength, Nm^{-2} , P is the applied load causing fracture, Newton, D is the diameter of the tablet, m and, t is its thickness, m. The BFI of the tablets were calculated using equation (1).

RESULTS AND DISCUSSION

Table 2 and Appendix 1 show the coating thicknesses obtained for the different concentrations of each of the coating materials. The values ranged between 1 and 68 molecules thick depending on the concentration and on the molecular size of the coating material. They were higher on the calcium carbonate than on the sodium salicylate, due to the differences in their densities and in their size distributions. At any particular concentration, silicone DC 200/50 produced the thickest coating because of its larger molecular cross-sectional area.

The results of the tensile tests on the tablets prepared by both the hand press and the Dartec were found to fit the general equation (York & Pilpel 1973)

$$\text{Log } T = AP_f + B \quad (6)$$

with a correlation coefficient >0.95 . P_f is the packing fraction, A and B are constants which depend on the nature of the powder and on the nature and amount of the coating material used.

In Fig. 2a, b, the log tensile strengths of the tablets at a fixed packing fraction of 0.89 for sodium

Table 2. Coating thicknesses on sodium salicylate (surface area $0.683 \text{ m}^2 \text{ g}^{-1}$) and on calcium carbonate (surface area $0.405 \text{ m}^2 \text{ g}^{-1}$)

Coating	Area per molecule $\times 10^{20} \text{ m}^2 \text{ g}^{-1}$	Concn of coating $\times 10^6$ mol g^{-1}	% w/w	Coating thickness (molecular layers)	
				Sodium salicylate	Calcium carbonate
DC 200/20	210.0	0.5	0.037	0.93 \approx 1	1.56 \approx 2
		1.0	0.075	1.85 \approx 2	3.12 \approx 3
		2.0	0.150	3.71 \approx 4	6.25 \approx 6
		5.0	0.375	9.29 \approx 9	15.62 \approx 16
		5.0	0.172	4.02 \approx 4	6.78 \approx 7
DC 200/50	912.0	5.0	1.725	40.20 \approx 40	67.81 \approx 68
		5.0	0.064	1.15 \approx 1	1.93 \approx 2
Tween 40	259.7	1.0	0.128	2.30 \approx 2	3.86 \approx 4
		2.0	0.227	4.60 \approx 5	7.72 \approx 8
		5.0	0.642	11.50 \approx 12	19.31 \approx 19
		5.0	0.066	1.19 \approx 1	2.00 \approx 2
Tween 60	269.0	5.0	0.656	11.86 \approx 12	20.00 \approx 20

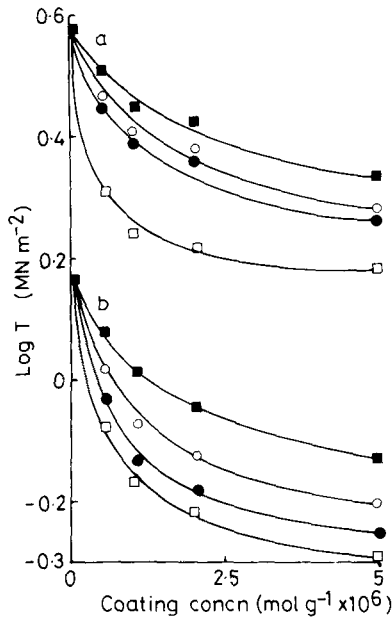


FIG. 2. Effect of coating concentration on tensile strength. ■ Silicone DC 200/20, □ silicone DC 200/50, ○ polysorbate 40, ● polysorbate 60. a, Sodium salicylate. b, Calcium carbonate.

salicylate and 0.76 for calcium carbonate (selected because they involved minimum extrapolation of the linear plots of $\log T$ vs P_f) are plotted against the concentrations of the applied coatings. It is seen that the tensile strengths decreased with increase in coating concentration. This can be ascribed to the coating material acting as a lubricant forming a mono or multilayer (see Table 2) on the surfaces of the particles (depending on concentration) which reduces the van der Waal's bonding forces between them (York & Pilpel 1973; Pilpel & Hephher 1977; Malamataris & Pilpel 1983).

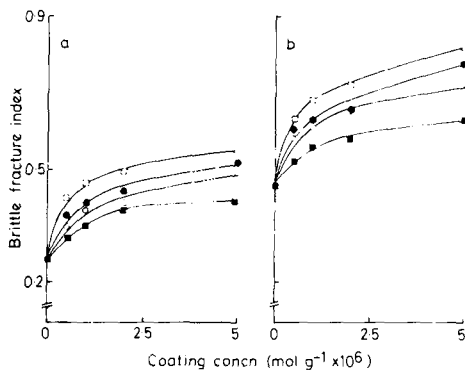


FIG. 3. Effect of coating concentration on the brittle fracture indices. Symbols as in Fig. 2.

Fig. 3a, and b show that the brittle fracture indices (BFI) of both powders increased with the amount of coating on the particles, the curves being approximately the inverse of those in Fig. 2a, and b, respectively, both in regard to general shape and in regard to their relative positions. This is as expected on the basis of the definition of BFI. From Table 3 it can be inferred that sodium salicylate is more plastic than calcium carbonate and the addition of the coating materials tended to make them less plastic. Thus, coated calcium carbonate tablets generally tended to cap or laminate when the BFI value was >0.7 .

Table 3 also shows that in all cases increasing the amount of coating caused decrease in the apparent plastic compression and an increase in the ratio ER/PC. This result accords well with those of Rees & Rue (1978) and Bangudu & Pilpel (1985) and it may be presumed that the coatings on the powder particles made it easier for them to slide past each other during compression, preventing them from interlocking and thus decreasing the number and strength of bonds between them (York & Pilpel 1973; Igwilo & Pilpel 1983). The tensile strengths at the selected packing fractions were inversely proportional to the ratio ER/PC (see Fig. 4a, b) and the BFI was a linear function of ER/PC (see Fig. 5a, b). A similar plot of T vs ER/PC in which all the points could be accommodated on a single straight line, see Fig. 4a, b, was reported recently for some other

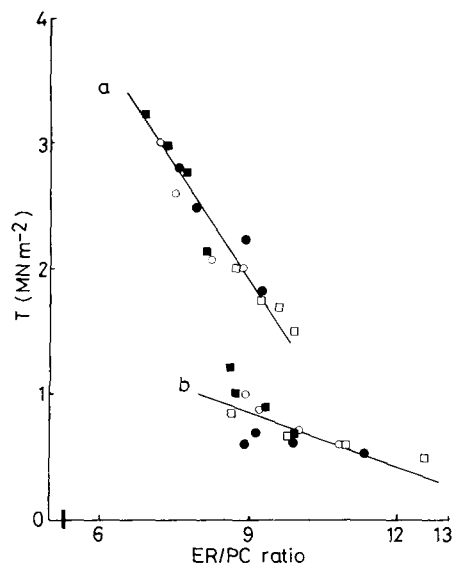


FIG. 4. Variation of tensile strength, T , with plasticity ratio, ER/PC. Symbols as in Fig. 2.

Table 3. Coating concentrations, plasto-elastic parameters, brittle fracture indices, tensile strengths and Heckel constants for

Sodium salicylate (0-20 μm)								
Coating	Concn mol g^{-1} $\times 10^6$	Plastic compression (PC) %	Elastic recovery (ER) %	ER/PC	BFI	Tensile strengths at P_f 0.89 MNm^{-2}	$K_H \times 10^3$ $(\text{MNm}^{-2})^{-1}$	A_H
None	None	1.75	11.5	6.57	0.260	3.837	2.59	0.701
DC200/20	0.5	1.60	11.0	6.88	0.320	3.206	2.63	0.723
	1.0	1.65	12.0	7.27	0.350	2.884	2.95	0.732
	2.0	1.50	11.50	7.67	0.394	2.679	3.05	0.766
	5.0	1.40	12.20	8.13	0.410	2.133	3.26	0.791
	DC200/50	0.5	1.40	12.20	8.71	0.424	2.051	2.91
DC200/50	1.0	1.30	11.90	9.15	0.456	1.750	3.23	0.737
	2.0	1.20	11.50	9.60	0.488	1.652	3.28	0.781
	5.0	1.20	11.90	9.92	0.564	1.514	3.73	0.782
Tween 40	0.5	1.60	11.50	7.19	0.352	2.979	2.69	0.728
	1.0	1.60	12.0	7.50	0.378	2.559	2.99	0.738
	2.0	1.40	11.50	8.20	0.414	2.399	3.14	0.768
	5.0	1.30	11.50	8.80	0.495	1.905	3.35	0.795
Tween 60	0.5	1.60	12.10	7.56	0.371	2.818	2.78	0.729
	1.0	1.50	11.90	7.90	0.408	2.443	3.11	0.740
	2.0	1.40	12.50	8.90	0.439	2.286	3.11	0.780
	5.0	1.30	11.90	9.20	0.517	1.811	3.45	0.801
Calcium carbonate (0-20 μm)								
Coating	Concn mol g^{-1} $\times 10^6$	Plastic compression (PC) %	Elastic recovery (ER) %	ER/PC	BFI	Tensile strength at P_f 0.76 MNm^{-2}	$K_H \times 10^3$ $(\text{MNm}^{-2})^{-1}$	A_H
None	None	1.50	12.2	8.13	0.462	1.496	1.64	0.373
DC200/20	0.5	1.40	12.00	8.57	0.522	1.216	1.63	0.389
	1.0	1.40	12.20	8.70	0.561	1.019	1.69	0.432
	2.0	1.30	12.60	9.30	0.582	0.891	1.71	0.474
	5.0	1.20	11.8	9.85	0.625	0.741	1.78	0.530
	DC200/50	0.5	1.40	12.00	8.60	0.630	0.841	1.73
DC200/50	1.0	1.30	12.80	9.78	0.678	0.679	1.75	0.458
	2.0	1.10	13.50	10.90	0.718	0.596	1.81	0.511
	5.0	0.98	13.50	12.50	0.815	0.518	1.85	0.592
	Tween 40	0.5	1.40	12.50	8.90	0.578	1.047	1.73
Tween 40	1.0	1.30	12.00	9.20	0.609	0.841	1.79	0.404
	2.0	1.30	12.80	9.90	0.638	0.750	1.79	0.476
	5.0	1.20	13.00	10.80	0.716	0.624	1.78	0.330
	Tween 60	0.5	1.40	12.40	8.90	0.608	0.933	1.75
Tween 60	1.0	1.40	12.60	9.10	0.630	0.741	1.72	0.447
	2.0	1.30	12.80	9.80	0.660	0.668	1.84	0.479
	5.0	1.10	12.20	11.40	0.768	0.562	1.81	0.569

pharmaceutical powders and their mixtures (Malamaris et al 1984; Bangudu & Pilpel 1985), and the significance of the plot is that in general those samples of coated sodium salicylate for which the ratio ER/PC <10 could be formed into satisfactory tablets with a packing fraction of 0.89. For coated calcium carbonate, however, for which the ratio ER/PC was always >8.5, the tablets at packing fraction of 0.76 all had a tendency to cap or laminate. The linear relationship between the BFI and the

ER/PC ratio, Fig. 5a, b, is not unexpected since both parameters are measuring essentially the same property of the coated materials, i.e. 'plasto-elasticity'. Increasing the amount of coating on the particles resulted in an increase in both parameters indicating that the coating, by acting as a lubricant, causes a decrease in apparent plastic deformation of particles inhibiting the formation of strong bonds between them.

The relationships between the applied pressure

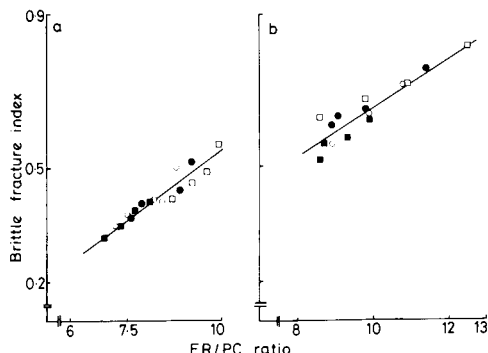


FIG. 5. Variation of brittle fracture index (BFI) with ER/PC ratio. Symbols as in Fig. 2.

(P) and the resulting packing fraction (P_f) of the uncoated and of some representative coated powders are plotted on the basis of the Heckel (1961) equation

$$\text{Log} \frac{1}{1 - P_f} = K_H P + A_H \quad (7)$$

in Figs 6a and b. A_H and K_H are physical constants for each material determined from the slope and intercept respectively of the extrapolated righthand linear portions of the graphs (Kurup & Pilpel 1978; Malamataris & Pilpel 1983). The term K_H is the

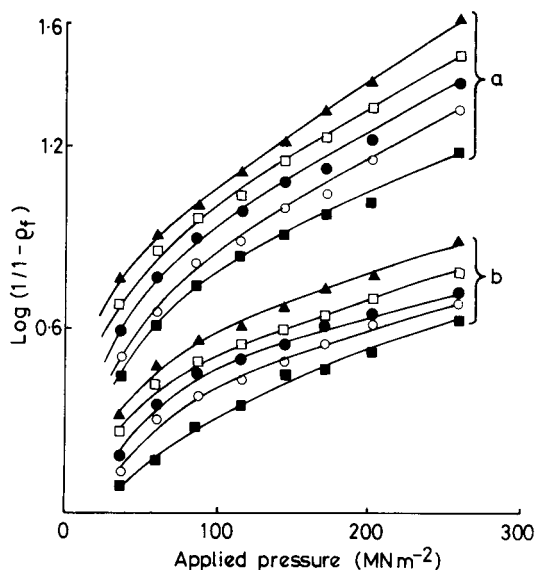


FIG. 6. Effect of coating with silicone DC 200/50 on Heckle plots. ■ None, ○ $0.5 \times 10^{-6} \text{ mol g}^{-1}$, ● $1.0 \times 10^{-6} \text{ mol g}^{-1}$, □ $2.0 \times 10^{-6} \text{ mol g}^{-1}$, ▲ $5.0 \times 10^{-6} \text{ mol g}^{-1}$.

reciprocal of the yield pressure. A_H is a measure of densification due to slippage and rearrangement of particles and depends mainly on their size, shape and hardness (Heckel 1961; York & Pilpel 1973; Malamataris & Pilpel 1983). The values of A_H and K_H are listed in Table 3; both increase with increasing amounts of coating on the particles indicating as expected a decrease in the yield pressure ($1/K_H$) of the coated material.

Finally, it is seen from Tables 2 and 3, and Figs 2 and 3 that irrespective of whether the coating materials are hydrophobic or hydrophilic, the changes they produce in the values of T , BFI and the ratio ER/PC follow similar trends. Furthermore, it is seen that of all the coating materials, silicone DC 200/50 produced the greatest changes. It therefore appears to be the most effective as a lubricant, presumably because it has the highest molecular weight and therefore produces the thickest coating film around the particles.

Acknowledgement

Obi Ejiofor thanks the Science Research Council for financial support during the course of this investigation.

Appendix 1

Coating Thickness

To calculate the coating thicknesses on each particle, the following procedure was adopted:

The particle size parameters \bar{d} (mean effective diameter), \bar{S} (mean effective surface area per particle) and \bar{V} (mean effective volume per particle) obtained by optical microscopy were calculated from the particle size analyses (see Bin Baie 1982). For sodium salicylate the density is 1.675 g cm^{-3} , therefore, the volume of $1 \text{ g} = 0.597 \times 10^{-6} \text{ m}^3$. Mean effective volume per particle (\bar{V}) = $190.47 \times 10^{-18} \text{ m}^3$, therefore, number of particles per g = $(0.597 \times 10^{-6}) / (190 \times 10^{-18}) = 3.13 \times 10^9$. Total surface area per g of sodium salicylate = $\bar{S} \times 3.13 \times 10^9 = 0.683 \text{ m}^2 \text{ g}^{-1}$. Similarly the total surface area per g of calcium carbonate = $\bar{S} \times 5.88 \times 10^8 = 0.405 \text{ m}^2 \text{ g}^{-1}$. Since 1 g mole of each of the coating materials contains Avogadro's number (i.e. 6.03×10^{23} molecules), then the number of molecules at each concentration of coating material per g of the powder can be calculated. Multiplying this number by the cross-sectional area of the molecule of the coating material* and dividing by the surface area of 1g of the powder, yields the number of molecular layers in the coating. The results are given in Table 2.

* The areas per molecule of the coatings were calculated on the assumption that the molecules lie flat on the powder surface and that the bond lengths were as follows: C-H (0.109 nm); O-H (0.138 nm); C-O (0.151 nm); C-C (0.154 nm); Si-C (0.193 nm); Si-O (0.164 nm).

REFERENCES

- Bangudu, A. B., Pilpel, N.** (1985) *J. Pharm. Pharmacol.* 37: 289-293
- Bin Baie, S. B.** (1982) Ph.D. Thesis. Appendix 2, University of London
- David, S. T., Augsburg, L. L.** (1977) *J. Pharm. Sci.* 66: 155-159
- Fell, J. T., Newton, J. M.** (1970) *Ibid.* 59: 688-691
- Heckel, R. W.** (1961) *Trans. Metall. Soc. A.I.M.E.* 221: 671-675: 1001-1008
- Hiestand, E. N., Smith, D. P.** (1984) *Powd. Tech.* 38: 145-159
- Hiestand, E. N., Wells, J. E., Poet, C. B., Ochs, J. F.** (1977) *J. Pharm. Sci.* 66: 510-519
- Igwilo, C. I., Pilpel, N.** (1983) *Int. J. Pharmaceutics* 15: 73-85
- Jones, T. M.** (1977) in: Polderman, Armstrong (eds) *Formulation & preparation of dosage forms.* Elsevier, North Holland, pp 29-44
- Kreutler, C. J., Davis, W. W.** (1971) *J. Pharm. Sci.* 60: 1835-1838
- Krycer, I., Pope, D. G., Hersey, J. A.** (1982) *J. Pharm. Pharmacol.* 34: 802-804
- Kurup, T. R. R., Pilpel, N.** (1978) *Powd. Tech.* 19: 147-155
- Malamataris, S., Pilpel, N.** (1980) *Ibid.* 26: 205-211
- Malamataris, S., Pilpel, N.** (1983) *J. Pharm. Pharmacol.* 35: 1-6
- Malamataris, S., Bin-Baie, S., Pilpel, N.** (1984) *Ibid.* 36: 616-617
- Martindale: Extra Pharmacopoeia.** 28th Edn. (1982) Publishers—The Pharmaceutical Press. London
- Pilpel, N., Hephher, N. M.** (1977) *Mat. Sci. Eng.* 27: 89-95
- Rees, J. E., Rue, P. J.** (1978) *J. Pharm. Pharmacol.* 30: 601-607
- Schick, M. J., Benson, F. R.** (1967) in: Schick, M. J. (ed.) *Non-ionic surfactants.* Vol. 1. Arnold, London, pp 5, 285-286
- Weissberger, A.** (1949) in: *Physical Methods of Organic Chemistry.* 3rd Edn. 1: pp 135-137
- York, P., Pilpel, N.** (1973) *J. Pharm. Pharmacol.* 25: 1P-11P