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Comparison between and evaluation of some methods for the assessment of the sphericity of pellets

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Abstract

The shape of pellets, prepared by extrusion-spheronisation, has been assessed by the analysis of the two-dimensional images in the form of an elongation ratio (direct microscopic measurement), aspect ratio (image analysis), one-plane critical stability (OPCS) and a shape factor e_R (Podczeck and Newton, 1994) plus 3-dimensional characterisation by the Heywood shape coefficient and a permeametry shape factor (Eriksson et al., 1993). Steel ball bearings were used as a standard for each of the methods. The elongation and aspect ratio proved to be poor methods of distinguishing between the variations in shape of pellets within a batch nor particularly sensitive to measure differences between batches. OPCS and the shape factor, e_R, were more distinguishing in terms of detecting batch differences and inter-batch differences. The two-dimensional image methods ranked the batches in equivalent order of ranking. The Heywood shape coefficient gave the same ranking but the permeametry shape factor gave a significantly different ranking which could be associated with the surface texture of the spheres. © 1997 Elsevier Science B.V.

Keywords: Air permeametry; Aspect ratio; Eccentricity factor; Heywood shape factor; Image-analysis; One-plane critical stability; Pellets; Shape analysis

1. Introduction

The determination of the shape of particles presents several problems both theoretically and practically. One approach discussed by several authors, e.g. Heywood (1954), Beddow and Meloy (1980), involves the ambition of describing each shape by a unique number and presents the problem of reconstruction of a particle shape from the shape measure. Another approach involves the identification of the deviation in shape from a standard shape, e.g. a sphere. This latter

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approach is of particular concern to the pharmaceutical industry when applying quality standards to the sphericity of pellets for use as multi-particulate dosage forms. It is here understood that the particles which should be characterised are nearly spherical in shape. The problems are associated with the approach for assessing the shape, i.e. to describe solely the general geometrical shape of the particle or to describe also the geometry of the particle surface, and to define the degree of deviation from a smooth sphere which is acceptable in relationship to the processing of the pellets.

Lövgren and Lundberg (1989) described an approach based on the measurement of the length and width of a two dimensional image of the pellets. The shape factor was expressed as a % sphericity, where 100% corresponds to a perfect circle. Several other papers quote an aspect ratio also based on a two-dimensional image of the particle, e.g. Baert et al. (1992). Hellén and Yliruusi (1993) reported seven parameters derived from image analyses of granules. They claimed that the elongation (d_{max}/d_{min}) and roundness ($\frac{A}{\pi}\frac{d_{max}}{2}$) provided the best differentiation of the shape of a set of pellets. Care needs to be taken in defining the elongation by d_{max} and d_{min}, in that image analysers define these in different ways, which are not always in agreement with the definition of elongation used by Heywood (1954). Any measure based on the ratio between two particle diameters has its limitation since it will not evaluate surface texture nor differentiate between a sphere and a cube.

Chapman et al. (1988) have clearly shown that a measure often used to describe circularity, i.e. four times the squared perimeter (P) divided by the projected area (A) $\left(\frac{4P^2}{A}\right)$, will not provide a clear differentiation between pellets of different shape. As an alternative procedure the determination of the 'one plane critical stability' (OPCS) was suggested and shown to provide a clear differentiation of pellet shape characteristics (Chapman et al., 1988). Unfortunately the procedure requires individually tracing round the two-dimensional image of particles and uses a special computer software with a licensed routine which is not generally available.

Podczeck and Newton (1994) have developed a shape factor, denoted shape factor e_R, to characterise the quality of spheres, both in terms of their general shape and surface texture. The system is based on a computer analysis of a two-dimensional image generated by an image analyser and is based on assessing the departure from the spherical form and the presence of surface irregularities.

Eriksson et al. (1993) used a combination of the permeamtry surface area and the projected area diameter of particles as a method of assessment of the sphericity of pellets based on all three main dimensions of particles. Support for its use was provided by measurements of the 3rd particle dimension, i.e. the thickness, by the ring gap sizer (Nyström, 1978) and the derivation of Heywood's shape coefficient (Heywood, 1954).

In this study, the shape of nearly spherical pellets, collected from six different batches, has been determined by some of the different methods discussed above. The methods will be considered in terms of their measuring principle, their ability to distinguish between pellets of similar shape and the ease with which they can be undertaken. Approximately equivalent diameter ball bearings have been used as a reference standard.

2. Materials and methods

2.1. Materials

From six batches of pellets, consisting of lactose and microcrystalline cellulose mixtures (in the proportions 85/15% by weight) and prepared by extrusion-spheronisation, the sieve fraction of 0.9–1.0 mm was collected. For more details on the preparation procedure for the pellets, see Eriksson et al. (1993). The pellets were visually rank ordered with respect to their shape and designated A to F.

Ball bearings of stainless steel (SKF, Sweden) were chosen as reference material since the steel balls are considered as ideal spheres with an extremely narrow size distribution and with a smooth surface. The steel balls are used as supplied and their diameter was 1000 μm and their

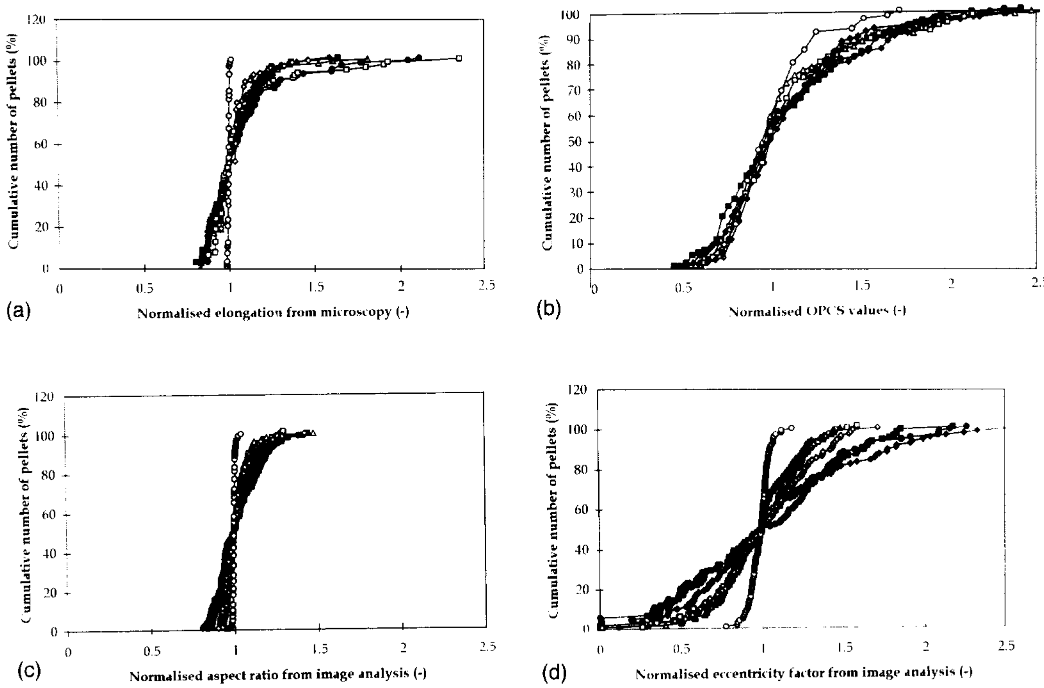

Fig. 1. Normalised distribution of, (a) elongation ratio determined by microscopy, (b) OPCS, (c) aspect ratio, and (d) eccentricity factor, e_R, for pellets: (◆) A; (■) B; (●) C; (□) D; (△) E; (◇) F; (○) S.

density 7.7 g/cm^3. The maximum variation in diameter given by the supplier was between 95 and 1005 μm.

2.2. Elongation, Heywood shape coefficient, permeametry surface area and permeametry shape factor

Values for elongation, Heywood shape coefficient, permeametry surface area and permeametry shape factor were taken from a previous publication (Eriksson et al., 1993). The elongation is defined as given by Heywood (1954).

2.3. One plane critical stability

The one plane critical stability was determined as described by Chapman et al. (1988). One hundred pellets from each type were measured.

2.4. Shape factor, e_R

By the aid of an image analyser (Seescan Solitair 512, Cambridge, UK) fitted with a black and white camera (CCD-4 miniature video camera modul, Rengo Co., Ltd., Toyohashi, Japan) connected to a zoom lens (18-108/2.5, Olympus, Hamburg, Germany), the shape factor e_R, for the pellets was determined as described by Podczeck and Newton (1994). One hundred pellets from each type were measured. For each pellet, 360 distances from the centre of gravity of the pellets was measured for the calculation of the mean radius of the equivalent circle.

2.5. Aspect ratio

The same image analyser as described above was used for the determination of an aspect ratio for the pellets. One hundred pellets for each type were measured. The aspect ratio is here defined as

Table 1
Median inter-quartile range (QR) and normalised inter-quartile range for the pellets and the steelballs

Methods	Materials	Median	QR	Normalised QR[a]
Image analyser: aspect ratio	A	1.253	0.189	0.126
	B	1.228	0.241	0.196
	C	1.192	0.210	0.176
	D	1.098	0.098	0.090
	E	1.095	0.087	0.080
	F	1.122	0.114	0.102
	S	1.030	0.014	0.014
Image analyser: eccentricity factor	A	0.286	0.169	0.591
	B	0.322	0.233	0.724
	C	0.361	0.253	0.701
	D	0.497	0.188	0.378
	E	0.521	0.163	0.313
	F	0.460	0.193	0.419
	S	0.685	0.056	0.082
OPCS	A	27	13	0.482
	B	29	15	0.518
	C	25	11	0.440
	D	21	8	0.380
	E	21	6	0.286
	F	22	7	0.318
	S	15	4	0.266
Microscopy: elongation	A	1.210	0.214	0.174
	B	1.250	0.257	0.206
	C	1.200	0.227	0.184
	D	1.143	0.144	0.126
	E	1.100	0.140	0.128
	F	1.053	0.052	0.050
	S	1.006	0.011	0.011

[a] QR divided by the median values

the longest Feret diameter over the Feret diameter perpendicular to the longest. For each pellet, 36 Feret diameters were measured.

3. Results and discussion

The shape and shape distribution for the 100 of each of the pellets was described by a cumulative number/shape graph. As the shape parameters have widely different numerical values, depending on the method of measurement, the values for the factors were normalised by the median value. The normalised distribution functions for the pellets and the reference ball bearings, *S*, are shown in Fig. 1a–d. The median values and the values of the inter quartile range of the original and normalised distribution are presented in Table 1. Clearly only the values of the shape factor, e_R, approach that of a normal distribution and only these values would be worthy of use in statistical analysis which assumes a normal distribution. The elongation ratio and the aspect ratio have virtually no slope, which is also reflected in the low values for the inter quartile range. This indicated the insensitivity of these methods in detecting variability in the pellet shape. The low inter-quartile range values for the aspect ratio and shape factor, e_R, of the ball bearings by image analysis measurements reflects the reproducibility in the shape of this system as values for the pellets are considerably larger. The large inter quartile range values for the OPCS of the ball bearings probably reflects the operator dependence of this technique, as opposed to its sensitivity in determining roundness. Examination of Fig. 1b, however, indicates that this method is quite good at distinguishing between non-round and round pellets (note the high value for the normalised OPCS value in Fig. 1b). The method however, appears less efficient in separating the round from the nearly round pellets.

The question arises as to whether the methods characterise the pellets in the same order. Hence, the pellets were ranked in order of the shape assessment from this and previous studies. The ranks were compared by Spearman's rank correlation (Table 2). It is clear that methods based on two dimensional images always provide the same rank order. The method which shows no correlation to the other methods is that of air permeametry. This is a method based on 3-dimensional aspects of the pellets but so is the Heywood shape factor which relates very well to the other methods. This difference could be associated with surface area measurement method and could be related to the surface roughness of the pellets or the problem related to the effective voidage of the powder bed, which could influence the flow of air past the pellets. That the ranking given by the shape factor, e_R, which also includes a measure of the surface roughness, comes closest to that of surface area (Table 2), supports this argument. Hawkins (1993) in particular, emphasises the difference between shape, which involves the form of the particles especially roundness and sharp corners, and texture, which associated with the surface roughness of a particle. Air permeability measurements could also involve the flow of air through pores within the pellets, which would not be reflected in any method which considers surface outline in two dimensional measurements of images.

Table 2
Comparison of the ranking of the medium roundness of pellets by aspect ratio, eccentricity factor, elongation ratio, Heywood shape factor and permeametry surface area

Methods		Spearman's rank correlation values
OPCS	Eccentricity (IA)	0.943*
	Aspect ratio (IA)	0.943*
	Surface area	0.771
	Elongation (M)	0.829*
	Heywood shape coefficient	0.829*
Eccentricity (IA)	Aspect ratio (IA)	1.000*
	Surface area	0.829
	Elongation (M)	0.771
	Heywood shape coefficient	0.771
Aspect ratio (IA)	Surface area	0.829*
	Elongation (M)	0.771
	Heywood shape coefficient	0.771
Surface area	Elongation (M)	0.600
	Heywood shape coefficient	0.600
Elongation (M)	Heywood shape coefficient	1.000*

IA, image analysis.
M, microscopy.
Surface area, permeametry surface area (Eriksson et al., 1993).
OPCS, one plane critical stability (Chapman et al., 1988).
* Significant on a 5 % level.

4. Conclusions

Images which only have two dimensions to represent pellet roundness are not an effective method in defining their quality. Improved representation is given by both the measurement of OPCS and the shape factor, e_R. The former is, however, operator-dependent and not readily accessible for general use. The latter is far easier to operate. The use of techniques based on assessment associated with three dimensions, shows that the time consuming Heywood's shape factors correlates well with the two dimensional methods but that air permeability ranks spheres in a different order of roundness. This could be related to the surface texture of the pellets or permeability of air through pores within the pellets. The methods is rapid and could be used as a quality control procedure.

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