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PARTICLE SHAPE DISCRIMINATION USING SLOTTED SIEVES

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ABSTRACT

A set of sieves having rectangular apertures has been used, with a set of square-mesh sieves, to separate powder particles according to their shape. A free-flowing granular material, sodium perborate tetrahydrate, was shape-sorted using the slotted sieves and also using an inclined, vibrating deck.

The length, width, thickness, projected area diameter and equivalent volume diameter were determined for each shape-fraction and these data were used to calculate shape factors to assess the performances of the two methods

It was found that both methods were capable of sorting the material according to particle shape. The deck was capable of

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a slightly higher throughput, but the sieves were more selective as well as being quantitative with respect to two of a particle's three principal dimensions.

INTRODUCTION

The size and shape of particles are of great importance in solids handling and processing operations because of their effects on the bulk and flow properties of powders and granulates A powder consisting of mainly irregularly-shaped particles has a lower poured bulk density than a powder of the same substance consisting of more regular, spherical particles. Its resistance to shear is greater and its ability to flow and mix with other powders is less. The effects of particle shape increase as particle size decreases until, at sizes of about 50µm or below, shape effects can predominate over size effects. This can significantly affect tabletting and capsule filling operations.

Within the last two decades, various methods for shape-sorting particulate solids have been developed, making it possible to investigate the effects of particle shape on powder properties. The most successful technique so far described uses the Jeffrey-Galion vibratory shape-sorter, a device originally designed to sort industrial diamond grit[1]. This machine can shape-sort particles ranging in size from a few millimetres down to about 200µm, but the throughput falls over this range from several kilograms a day to less than 50g.

Nakajima et al[2] used square-mesh and slotted sieves to shape-sort fragments of crushed hæmatite in the size-range 5-50mm. The principle of the method is that square- or round-hole sieves will separate particles according to their width, w, whereas slotted sieves separate according to particle thickness, t. The method was highly selective and, although only two dimensions were measured, it accounted for almost all of the shape variation in the particles because Nakajima and his co-workers found that particle length, l, did not differ significantly between fractions.

In the work presented here, the ability of slotted sieves to shape-sort much smaller particles has been assessed, and the method's performance has been compared with that of the Jeffrey-Galion shape-sorter.

MATERIALS AND METHODS

Sample Preparation

Sodium perborate tetrahydrate (BDH Ltd., Poole, England) is a bleach used in detergent powders and in some oral hygiene preparations. It is available as granular particles of similar size and shape to many pharmaceutical granulates. To eradicate particle size effects as far as possible, a bulk sample of sodium perborate was closely-sized by sieving on a nest of square-mesh sieves, arranged in a $\sqrt[4]{2}$ series.

The 425-355µm size-fraction was divided using an Endecotts ½" sample splitter to give two sub-fractions, one of which was sieved on a nest of slotted sieves, again arranged in a $\sqrt[4]{2}$ series. The sieve cloths were electroformed, having slots whose lengths were three times greater than their widths. The slot widths corresponded with the aperture sizes in a standard ASTM E11 $\sqrt[4]{2}$ series of square-mesh sieves. The largest slotted sieve used was 420µm and the smallest was 210µm. A smaller sieve could not be used since a particle passing a 425um square aperture could have a width, w, of up to 600µm if it passed diagonally (see Figure 1).

Because the length of the slots is three times their width, to prevent a particle of width 600µm being retained in a slot due to its width rather than its thickness, the smallest slot we can use is 600/3 = 200µm.

The sieves were shaken on a Fritsch Analysette 3 electromagnetic test sieve shaker (Fritsch, W. Germany). Preliminary experimentation showed the best sieving regime to be 15 minutes at an amplitude of 0.5mm with a load of 20g.

The remaining sub-fraction was sorted on the Jeffrey-Galion shape-sorter (Figure 2). This device consists of a triangular deck, mounted on a tubular metal framework, fitted with two screw-jacks to permit adjustment in two perpendicular directions. Material is fed onto the deck at the rear corner and the vibrating deck imparts an upward momentum to the particles, which tends to make them ride up the deck in the direction of the sorting angle. A feed angle of as little as 2.5° is sufficient to make the particles

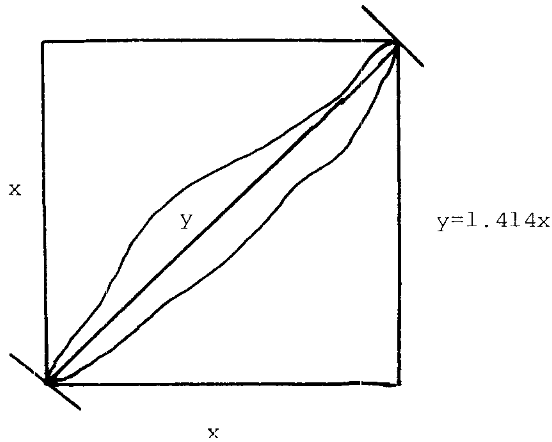

FIGURE 1

Diagram of a Square Aperture Showing Maximum Possible Particle Width (Y)

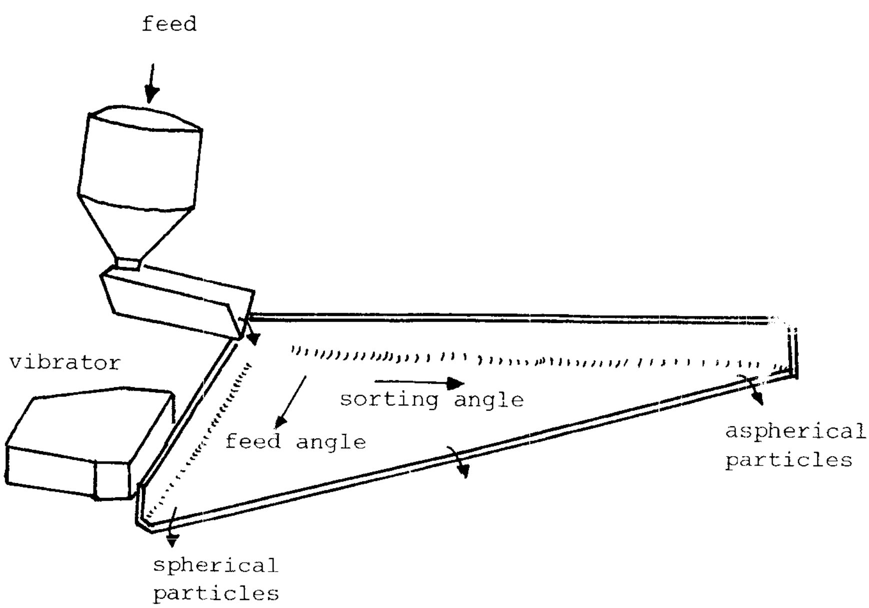

FIGURE 2

Diagram of the Jeffrey-Galion Shape-sorter ride not only upwards but also forwards over the deck. The result is that spherical particles leave the deck at the lowest point of the exit edge, whilst flaky or blocky particles leave at the highest point of the same edge. Thirteen catchpots collect the different shape-fractions which emerge at the front edge of the deck.

The shape-fractions produced were reduced to samples of 5-10g using the Endecotts sample splitter and these smaller samples were further reduced by pouring over a knife-edge until only a few thousand particles remained. The particles used for shape characterisation were extracted from these samples.

Sample Characterisation

The thicknesses, t, of 100 particles from each shape-fraction were measured using a D.C. miniature displacement transducer (DFg 2.5 (Gold) - Sangamo, Bognor Regis, England). This had a rated stroke of 2.5mm and a linearity of 0.1%. Particles were allowed to come to rest on a glass slide in their most stable orientation and were then manœvred under the probe of the rigidly-mounted transducer using microsurgical forceps, so that their heights could be measured. A minimum of three measurements were made for each particle to ensure accuracy and reproducibility.

The particles from each fraction whose heights had been determined were examined using a microcomputer-based image-analysis rig. The apparatus used is shown diagrammatically in Figure 3. It comprised a Vickers M75 microscope (Vickers(Instruments)

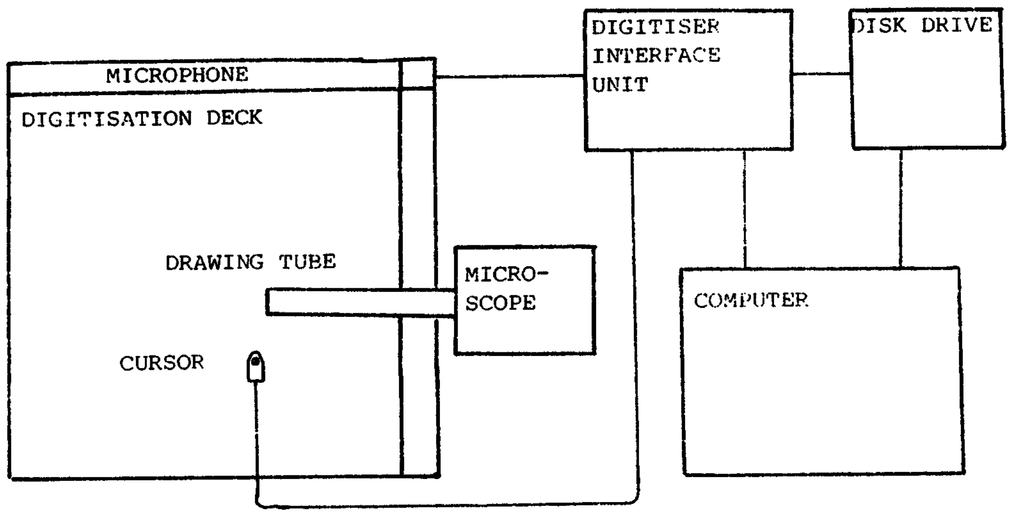

FIGURE 3

Block Diagram of Microcomputer-based Image-analysis Rig

Ltd., York, England) fitted with a drawing tube. The drawing tube allowed the image of the adjacent digitisation deck and cursor (Science Accessories Corp., Southport, Conn., USA) to be superimposed on the particle profiles. To digitise a point on a particle profile the cursor's cross-wires are positioned on the profile and the trigger is depressed. This causes a spark to be emitted and microphones on two perpendicular sides of the deck record the sound made by the spark. The spark emission and microphones are controlled by a digitisation interface unit ([illegible] Instruments) Ltd., Maidenhead, England) which measures the time taken by the sound to reach each microphone and expresses the position of the cursor as a pair of x,y coordinates which are sent to the computer.

In the first instance particle length, l, and width, w, were measured. The particle thickness, t, was then entered into the computer so that all of the data could be sorted and a statistical analysis performed. In the second stage, the perimeter of each particle was digitised and the computer calculated the projected area diameter.

The density of the particles was measured using a Beckman model 930 air comparison pycnometer. The equivalent volume diameter was calculated from the mean particle volume for each shape fraction, which was in turn calculated by counting and weighing 1000 particles from each sample, then dividing the mean particle weight by the density.

Specific surface area was determined using a Lea and Nurse apparatus with a very short capillary (5cm), so that high air flowrates could be used. The measurements made were used to calculate the shape factors defined in Table 1.

RESULTS AND DISCUSSION

The thickness distribution for the slotted sieved material (Figure 4) is approximately Gaussian and, like conventional sieving distributions, it gives quantitative information about the particle thickness. The Jeffrey-Galion pot number distribution shown in Figure 5 is not so informative because although it tells us how much of each shape fraction there is, we do not know what

TABLE 1

Definitions of the Shape Factors used to Characterise the Particles

HEYWOOD (H1)	$\frac{f}{k}$ where $f=1.57+C(k_e/m)^{1.3}(n+1)/n$ and $k=k_e/m\sqrt{n}$
HEYWOOD (H2)	$S_w d_a D$
KRUMBEIN (K)	$\frac{wt}{l^2}$
WENTWORTH (W)	$\frac{l+w}{2t}$
ZINGG (Z)	$\frac{lt}{w^2}$

the shapes of the particles in each fraction are. The distribution is in any case dependent on the machine settings used.

The throughputs for the two methods were comparable, being about 500-1000g a day, though the deck could be operated continuously, while the sieving was a batchwise process.

The characterisation results are summarised in Table 2. The coefficients of variation for particle length and width are quite high and there is a tendency for these dimensions to decrease slightly with decreasing slot width. Particle thickness is the dimension which has most influence on the ability of particles to pass a slot and so thickness decreases with decreasing slot width. Thickness decreases to a much greater extent than length or

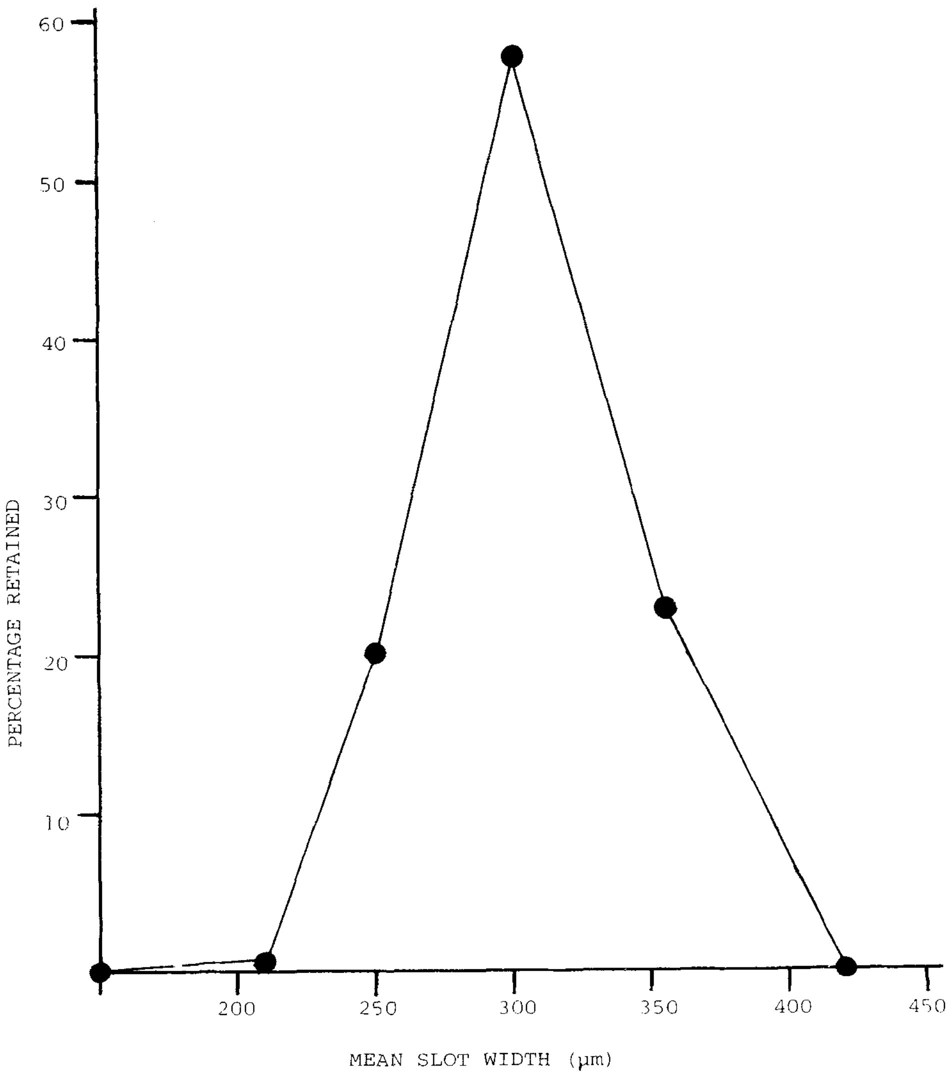

FIGURE 4

Slotted Sieving Distribution for Sodium Perborate 425-355μm

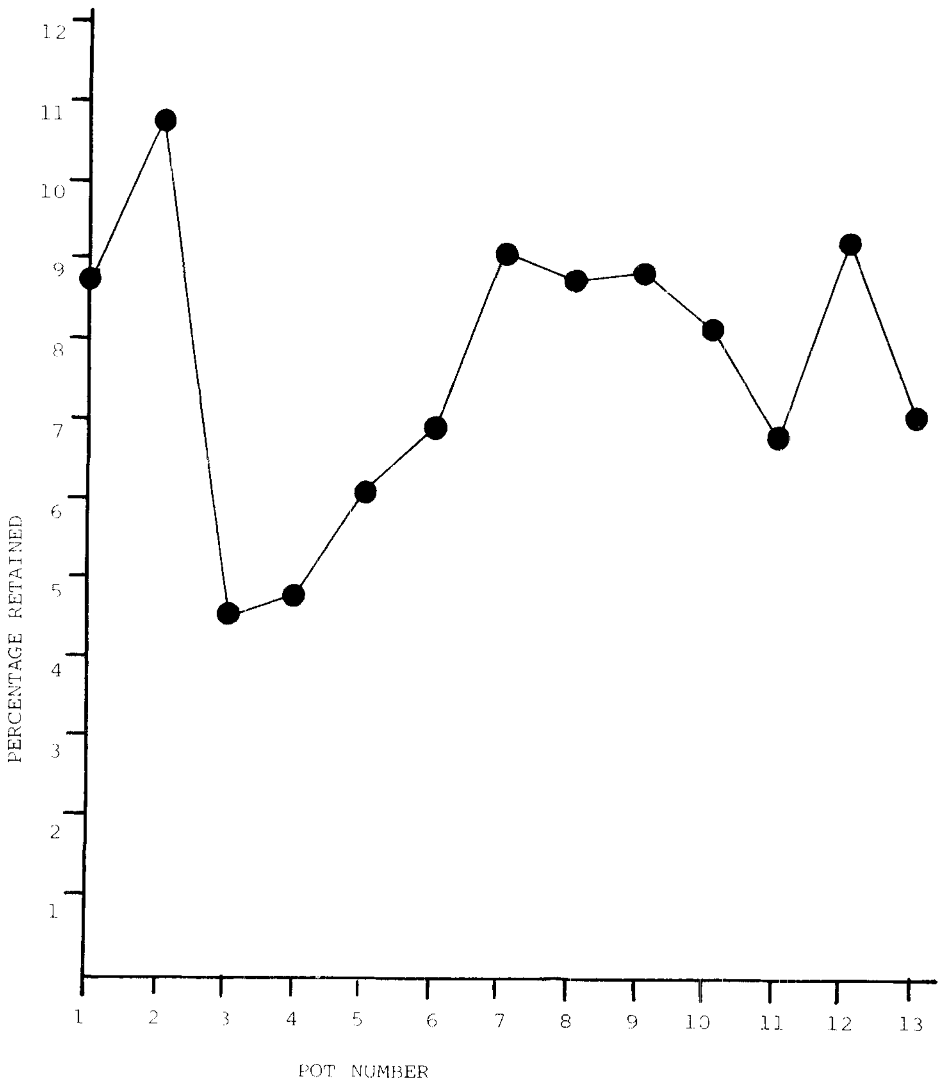

FIGURE 5

Jeffrey-Galion Pot Number Distribution for Sodium Perborate 425-355μm

TABLE 2

Characterisation Results for Sodium Perborate 425-355µm

	DECK SORTED				SLOTTED SIEVED			
	Pot 1	Pot 5	Pot 9	Pot 13	420-355µm	355-300µm	300-250µm	250-210µm
l(c.v.)	474(8.1)	470(14.1)	480(12.5)	507(15.0)	513(10.9)	488(12.2)	482(10.6)	466(13.0)
w(c.v.)	394(7.6)	384(9.3)	387(10.1)	433(14.1)	431(7.0)	399(8.9)	400(10.4)	376(14.4)
t(c.v.)	401(8.3)	361(9.3)	337(9.9)	322(10.8)	383(5.6)	335(8.0)	289(7.0)	241(8.5)
d_a	415	413	418	433	455	431	425	395
d_v	361	366	358	354	400	365	349	327
S_w	145.2	155.3	177.1	190.1	140.3	169.1	187.5	198.6

all dimensions are um, S_w is cm^2/g

width, the combined effect being a decrease in the equivalent volume diameter with decreasing slot width.

For the deck-sorted materials the coefficients of variation in each of the three dimensions are about the same, but for the slotted sieved samples there was less variation in thickness than in the other dimensions. Length and width increase with increasing pot number, causing an increase in projected area diameter. At the same time thickness decreases in such a way that the equivalent volume diameter does not change with pot number. This gives confirmation that the deck sorts according to particle shape and not by size (mass). The results highlight the different sorting mechanisms of the sieves and the deck: the sieves sort mainly by thickness, the deck by projected area (area of contact between the deck and particles).

The shape factors defined in Table 1 are plotted against mean slot width and pot number in Figures 6 and 7. Two methods of calculating the Heywood shape factor were employed to determine whether or not the shape can be represented by triaxial factors as effectively as by a factor which is calculated from bulk properties. In fact, both H1 and H2 show trends in shape with pot number and slot width, but they give numerically different results for the Heywood shape factor. The differences are probably due to the differing assumptions made in each case. The shape factors do all in fact show trends in shape between fractions, showing that although each method effectively sorts according to only two of a particle's three principal dimensions, the resultant fractions show trends in the overall particle shape.

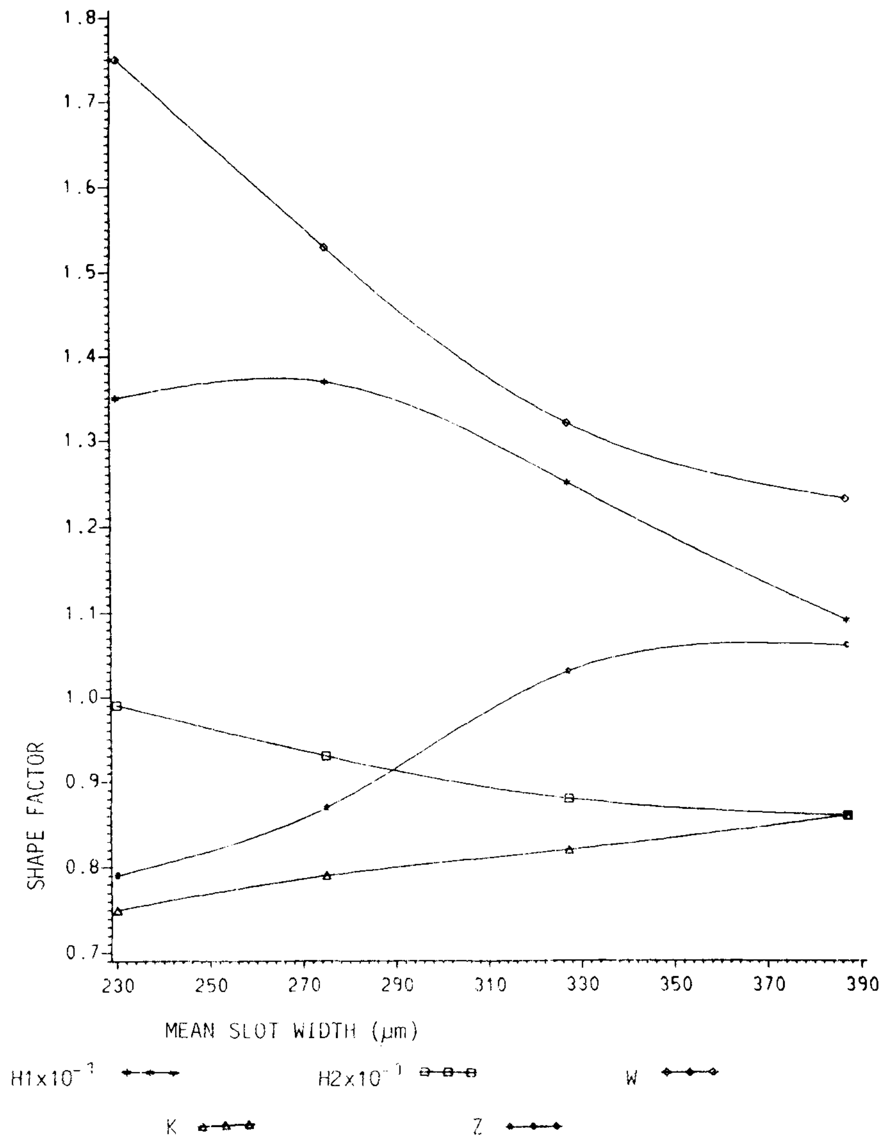

FIGURE 6

Plot of Shape Factors against Mean Slot Width for Sodium Perborate 425-355μm

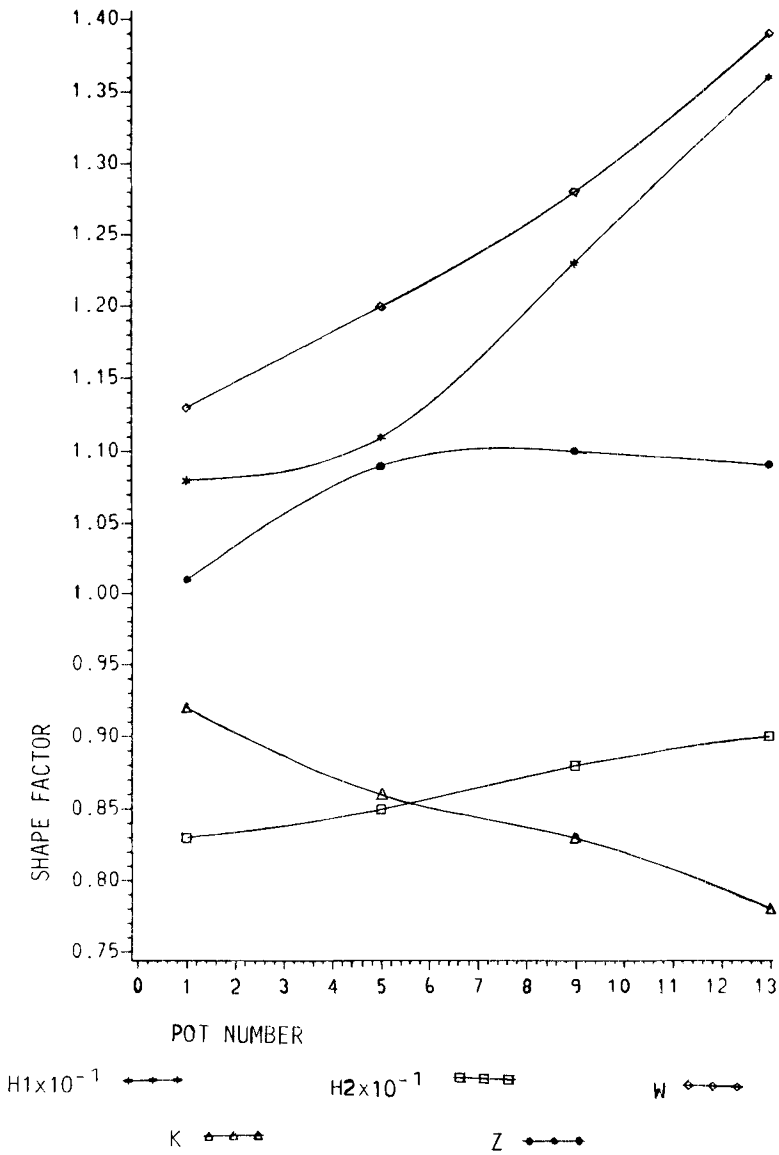

FIGURE 7

Plot of Shape Factors against Pot Number for Sodium Perborate 425-355μm

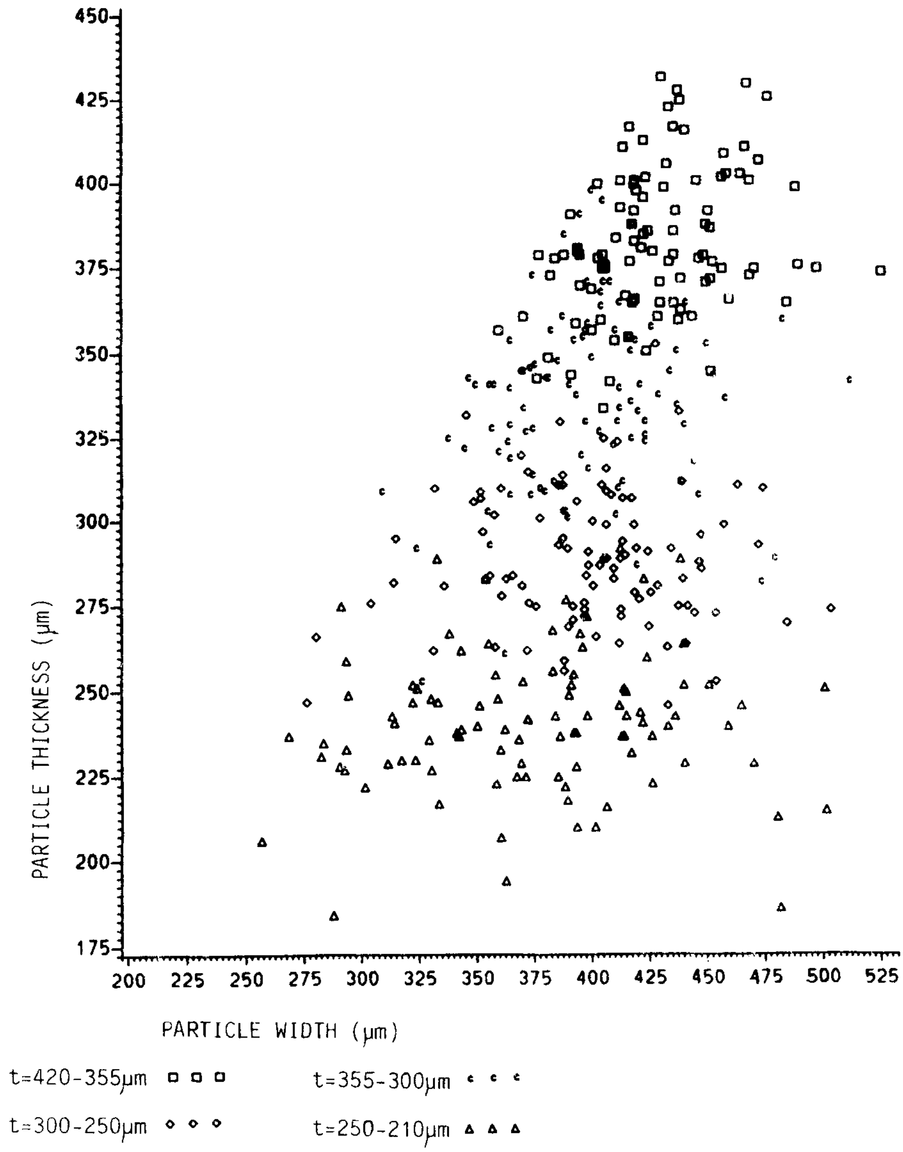

FIGURE 8

Selectivity Plot for Sodium Perborate 425-355μm on Slotted Sieves

TABLE 3

Sample Variances for Slotted Sieved and Deck Sorted Samples

Fraction	Variance	Fraction	Variance
t=420-355μm	4488	pot 1	3656
t=355-300μm	5509	pot 5	6868
t=300-250μm	4767	pot 9	6224
t=250-210μm	7045	pot 13	9989

Figure 8 illustrates the selectivity of the slotted sieving technique. The four horizontal layers represent the four thickness fractions and while there is considerable overlap between adjacent fractions, the boundaries do appear to correspond closely with the nominal slot widths of the sieves which delineate the fractions. Thus the separation is accurate, but somewhat less precise than that obtained by Nakajima et al[2]. This is because in the work reported here, sieving was performed entirely automatically, whereas Nakajima and co-workers were able to maually align their large hæmatite particles in the slots to facilitate passage. There is no comparable selectivity with the Jeffrey-Galion deck.

To quantify the within-fractions variability (sample homogeneity), the variances in each of the three principal dimensions were added together to give the total variance for each fraction. The results, shown in Table 3, reveal that there is generally less within-fractions variability for the slotted-sieved materials than for the deck-sorted samples. The lowest variability is exhibited by pot 1 of the deck-sorted material, but variability increases markedly with pot number.

CONCLUSIONS

The results show that sodium perborate tetrahydrate can be split into a number of shape fractions by either of the two methods used. The sieving method gives greater selectivity and greater sample homogeneity than the Jeffrey-Galion deck and has the further advantage that it is directly quantitative with respect to two of a particle's three principal dimensions.

Slotted sieves can be used for rigorous shape analysis, sample preparation or simply to measure particle width, providing a useful additional quality control specification for powders and granules. The method could also be useful in spheronisation processes, to screen out non-spherical particles.

Two of the main advantages of the slotted sieving technique are that it is simple to perform and requires a minimum of special equipment (only the sieves themselves). For these reasons, together with their selectivity and quantitative shape-sorting capability, we believe that slotted sieves have tremendous potential both in research and in quality control.

SYMBOLS

C constant depending on the physical form of a particle

D true density

d_a projected area diameter

f Heywood's surface coefficient

k Heywood's volume coefficient

k_e volume coefficient for an equidimensional particle

l particle length

m Heywood's flakiness ratio (m=w/t)

n Heywood's elongation ratio (n=l/w)

S_w specific surface area

t particle thickness

w particle width

ACKNOWLEDGEMENTS

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