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PARAMETRIC STUDY OF INCLINED PLANE SIEVING

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This paper presents the study of different parameters affecting the sieve fractionation of powders over an inclined plane. In this investigation coal powder has been used to see how the shape of the fineparticles modifies the behaviour of the powder moving down the inclined plane. It has been indicated that the mean size of the fractions of the powder passing through the sieve at different angles of inclination (θ) is essentially constant and is independent of the amount of the powder passed. The amount of powder passed through the sieves drops off drastically. In such a setup sieving could be very quickly achieved in relatively short distances. This investigation would be very important in developing automatic sieving procedures.

Keywords: Sieve fractionation, Inclined plane sieving, Automatic sieving.

Introduction

A completely reorganized sieving machine for the automated evaluation of sieve residues has been described by Kaye [1,2]. In this sieving system which is known as SORSI system, the fineparticles to be fractionated move over a piece of sieve cloth forming the base of a rotating sieving chamber [2]. This system has been utilized for the evaluation of different powders on the sieve [3-5,11,12,].

The kinetic residues measured with SORSI system for a given sieve appear to be considerably larger than the residues obtained by prolonged sieving because as pointed out by Kaye [3,6,7], the kinetic residue procedure tends to minimize the influence of the few large apertures present in the mesh aperture distribution whereas the prolonged sieving emphasizes the presence of these few apertures.

The basic postulate presented by Kaye and co-workers [1,3,11,12] has confirmed that the fineparticles which are smaller than the nominal size of the sieve aperture pass through the sieve very quickly even if fairly deep beds of powders are used.

A very efficient fractionation of powders on a sieving surface can be obtained by sending the powder in a thin layer over an inclined plane sieving cloth. It has been observed [3,7,12] that this type of sieving action minimizes the presence of large apertures. The completion of sieving action for fineparticles smaller than the nominal mesh aperture of the sieve [1,12] takes place in a relatively short distance over the sieving cloth.

The SORSI system was not that practical as it should be therefore, it was decided to carry out some experimental work on the kinetics of sieving over an inclined plane using pulverised coal to examine the reasons why SORSI system gave residues higher than those obtained with RO-Tap sieving machine [1,4,6,11,12,].

The purpose of using coal fineparticles in this study is to see how the shape of the fineparticles modifies the behaviour of the powder moving down the inclined plane sieving device.

Kinetics of fineparticles over an inclined plane. To consider the motion of fineparticles over an inclined plane, it is necessary to know the number of forces and their resultant acting on the fineparticles. Applying the Newtonian laws of motion to describe the kinetics of fineparticles, mass of the fineparticles and the forces acting upon them are considered. As a general rule, external forces may be exerted on the finepartiles at any point where the fineparticles touch the surface of the inclined plane. These forces are called Contact Forces.

In this study our interest is to choose a convenient coordinate system for the motion of coal fineparticles down the plane inclined to the horizontal at an angle θ(theta) as depicted in Fig. (1a). Newton's law, $F = m\, dx^2/dt^2$, where m is the mass of the fineparticles and x is the displacement of these fineparticles down the inclined plane, is applied in component form:

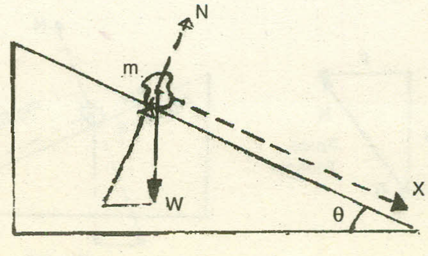

Fig. 1a.

Note: This work was carried out at the Physics & Astronomy department, Laurentian University, Sudbury, Ontario, Canada, P3E 2C6.

where N is the contact force exerted by the surface of the inclined plane, having a tangential component called the Force of Friction and a perpendicular component called the Normal Force. W is the weight of the fineparticles under consideration. Since the two forces are not in the same direction, they cannot add to zero and the layers of fineparticles must therefore, accelerate in the chosen coordinate frame with one parallel and the other perpendicular to the inclined plane as shown in Fig. (b).As indicated in Figs. (1a and 1b). The resultant force F is parallel to the plane. The force triangle and the space triangle are similar and theta (θ) is common to both the triangles. Since from the force triangle F = mg Sinθ, from the space triangle Sinθ = perpendicular/ hypotenuse, then acceleration has only one component, $dx^2/dt^2=a$. For this choice N is in the Y-direction and weight Wx has the components as follows:

$W_x = w \sin\theta = mg \sin\theta$, $W_y = -w \cos\theta = -mg \cos\theta$, where, m is the mass of the fineparticles rolling down the plane and g is the acceleration due to gravity as shown in Fig. 1b. The resultant force in Y-direction is equal to N- mg Cosθ. From Newton's second law, it can be shown that

$$dx^2/dt^2 = 0,\ F = m\, dx^2/dt^2 = N - mg \cos\theta,\ \text{or}\ N = mg \cos\theta,$$

Similarly, X- component, $F = m\, dx^2/dt^2 = mg \sin\theta$, or $a = g \sin\theta$. Note that the acceleration down the plane is constant and equal to g Sinθ. At the extreme values, θ = 0°, θ = 90°, the acceleration is of course zero at θ = 0°, i. e. a = g Sinθ =0. At the opposite extreme θ = 90°, the inclined plane is vertical, then the weight W, has only one X-component along the inclined plane and the normal force. N = mg Cos 90° = 0, the acceleration a = g Sinθ = g, since the fineparticles are in the free fall.

In this study the angle θ is varied from 10 to 65 degrees and the cases of θ=0 and θ=90 are not considered. Therefore, angles θ=65 degrees and 55 degrees are taken as maximum angles of inclination for measuring the amount of fineparticles passed through the sieve cloths and size distribution functions of the fineparticles respectively.

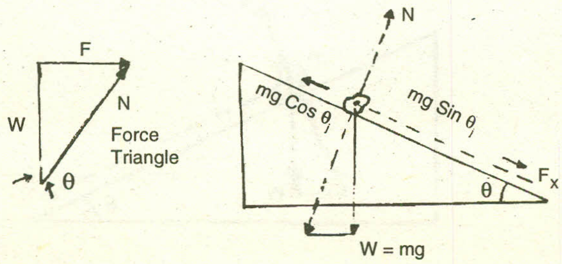

Fig. 1b.

Experimental

To investigate the sieving kinetics parametrically an apparatus as shown in Chart 1 was constructed and a layer of coal powder was made to move over its inclined plane and The width and length of the sieve cloths down the inclined plane were 7 and 10 cm respectively. This apparatus was used to explore the effect of different parameters such as angle of inclination on the fractionating performance of the sieve cloths as the powder is trickle-fed down the inclined plane. The sieve cloths used in this experiment were of 60 mesh (250 μm, nominal size), 120 mesh (125 μm, nominal size) and 230 mesh (63 μm, nominal size), coarse, medium and fine respectively.

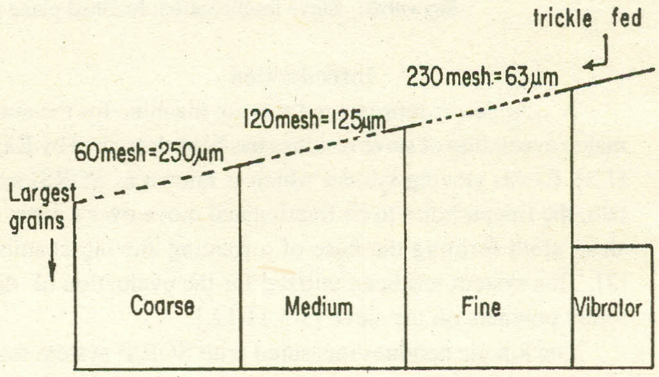

Chart 1. Inclined plane sieving apparatus.

The shape of a typical aperture in a wire-woven sieve is trapezoid as shown in Fig. 2a. In this communication the size of an aperture on the sieve surface as viewed through a microscope is taken to be the magnitude of the distance between the mid-point of the sides of the trapezoid. The microscope is fitted with an image shearing eye-piece [8,10,11,12]. The mesh aperture distribution of different sieve cloths as determined from the size distribution of glass beads trapped in the mesh apertures after few minutes sieving time was determined by direct inspection with microscope (Fig 3).

A sample of 20 g of coal powder was placed on the inclined plane sieving apparatus and vibrated by suitable arrangement provided by the Kenwood Company, Model 432 Electronic Vibrator.The angle of inclination was varied from 10 to 65 degrees to the horizontal and the amount of powder passing through the sieve cloths for these angles were measured.

Analysis of size distribution function of coal powder passed through different sieve cloths. When characterizing the size distribution of coal fineparticles it is essential to consider the fact that there is no straightforward method of describing the size of the irregular shaped fineparticles. It has

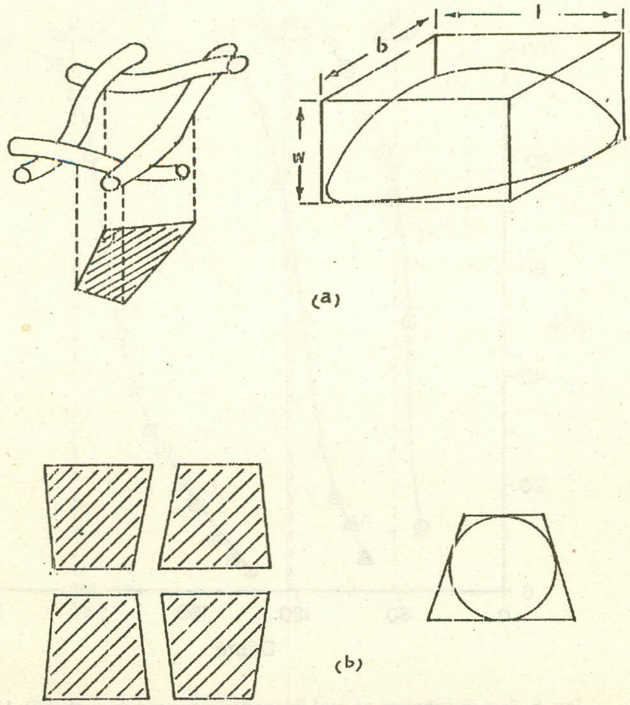

Fig. 2. (a) Apertures formed in a wire woven sieve are trapezoids. (b) The effective size of an aperture can usefully be defined by the size of the sphere just able to pass the sieve aperture.

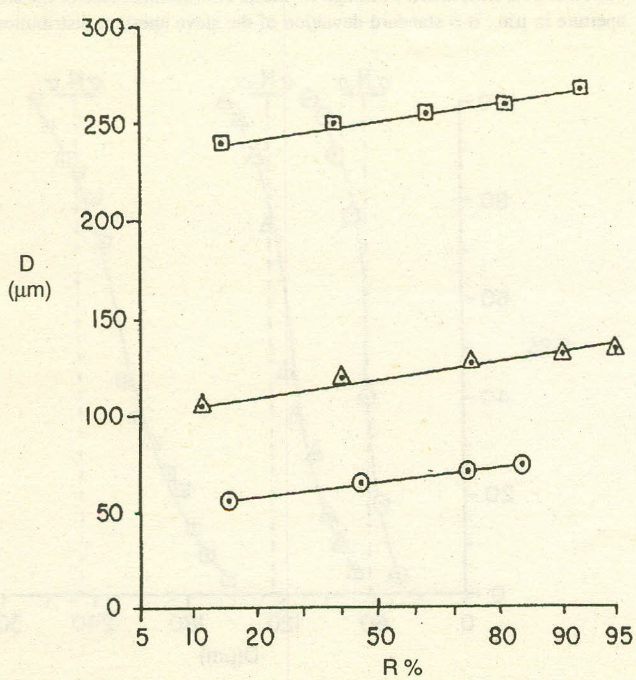

Fig.3. Mesh aperture distribution of three different sieve cloths, as determined from the size distribution of glass beads trapped in the mesh.

R% = number percentage of glass beads in μm. D = diameter of the glass beads in μm. ⊙ = 230 mesh sieve (nominal size 63 μm). Δ = 120 mesh sieve (nominal size 125 μm). ⊡ = 60 mesh sieve (nominal size 250 μm)

been proposed [6,11,12] that coal fine particles should be inspected through the image shearing microscope that they are in the position of maximum stability and that it is reasonable to assume that the third non-visible dimension is equal to the width of the fineparticle profile as examined through the microscope. On this basis the size parameter is based on the following mathematical relation:

$$D = \sqrt[3]{\frac{X}{W^2\ L}}$$

where W= width of the coal fineparticles.

L= length of the coal fineparticles.

This relationship can be used to describe the size of irregular shaped fineparticles. In order to establish the size distribution, 300 fineparticles were viewed through the image shearing microscope; the length and width of coal fineparticles were measured using this instrument. This image shearing technique, originally developed by Tumbrel [1,8,10-12] exhibited two images separated by special prisms which can be rotated. The two images of the aperture size are moved with respect to each other as shown in Fig. 4. First the two images are coincident then one image is moved from the other. Thus the various dimensions of the apertures of the sieve cloths and the size distributions of the coal fineparticles can be determined. The size distribution functions of 300 coal fineparticles for 10, 35 and 55 degrees with respect to the horizontal were examined for this study.

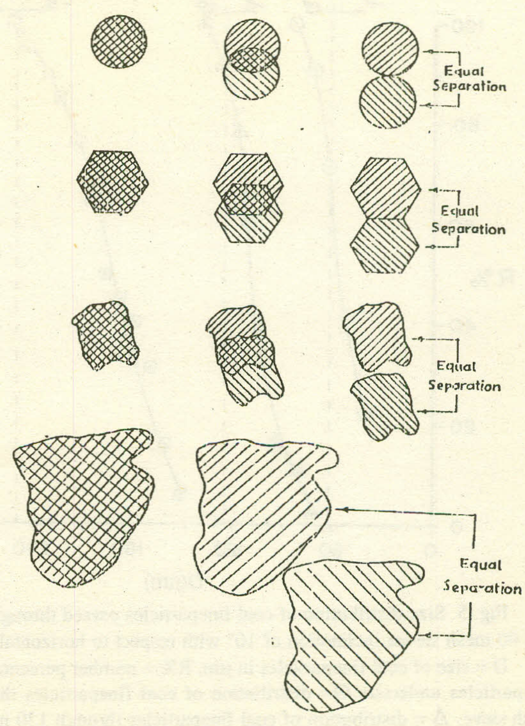

Fig. 4. In the image shearing technique for characterizing fineparticle profiles two images of the profile are moved relative to each other until they are just separated.

Results and Discussions

To study the different parameters which affect the sieving kinetics over an inclined plane, the experiments are carried out using pulverised mineral coal to highlight any essential difference between the probability of passage of smooth and irregular fineparticles through different sieve meshes. The aperture distribution of the sieves as shown in Fig. 3. and the size distribution of the coal fineparticles passing through various sieves at different angles of inclinations are Gaussian distribution functions.

In this communication only 10, 35 and 55 degrees inclinations are used for the size analysis. The data for these angles is summarized in Figs. 5-7. It can be seen that in all cases the size of the fineparticles passing through the sieve does not depend on the angle of inclination, whereas the amount of powder does. This fact demonstrates that the probability of the passage through the sieve is governed by the accessibility to the sieving surface . As the angle of inclination increases, there is a tendency of the powder to gain kinetic energy (1/2 m v2 =E) and to flow over the apertures of the sieve cloths rather than to pass through these apertures. In Fig. 8, it has been indicated that the mean size of the fractions of the powder passing through the sieves at different angles of inclinations (θ) is essentially constant and independent of the amount of the powder passed.

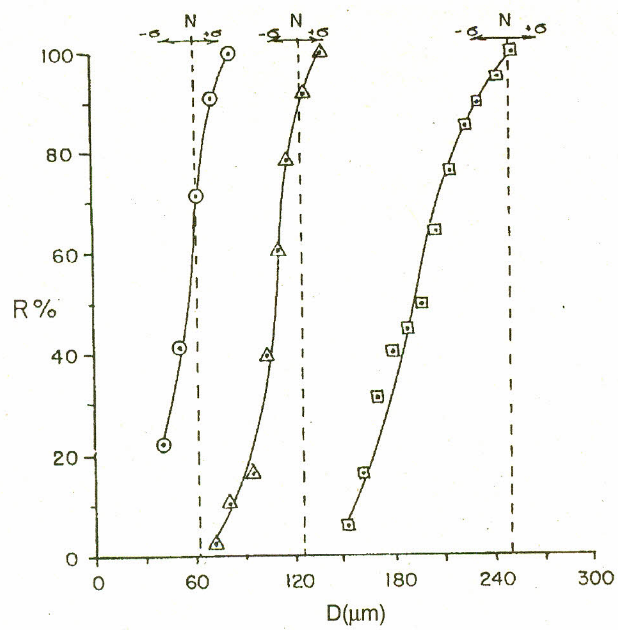

Fig. 5. Size distribution of coal fineparticles passed through 230, 120 and 60 mesh sieves inclination of 10° with respect to horizontal plane.

D = size of coal fineparticles in μm. R% = number percentage of coal fineparticles undersize. ⊙= distribution of coal fineparticles through 230 mesh sieve. Δ = distribution of coal fineparticles through 120 mesh sieve. ⊡= distribution of coal fineparticles through 60 mesh sieve. N = nominal size of the sieve aperture in μm. σ = standard deviation of the sieve aperture distribution.

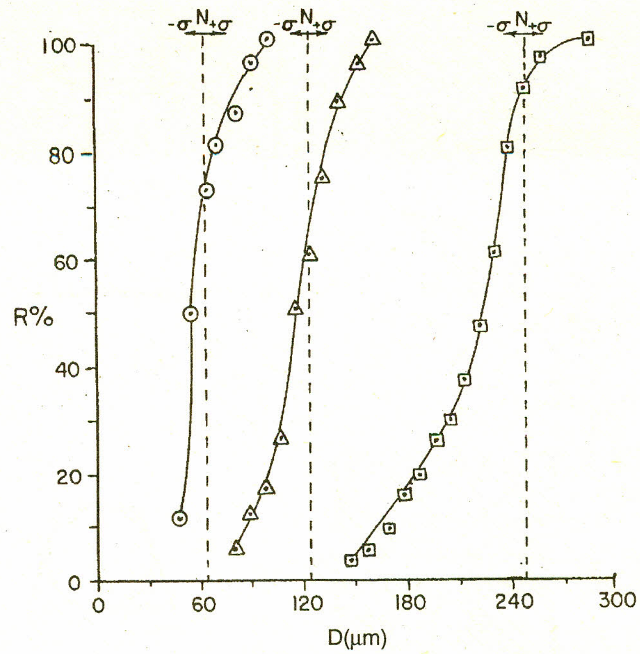

Fig. 6. Size distribution of coal fineparticles passed through 230, 120 and 60 mesh sieves. Inclination of 35° with respect to horizontal plane.

D = size of coal fineparticles in μm. R% = number percentage of coal fineparticles undersize. ⊙ = distribution of coal fineparticles through 230 mesh. Δ = distribution of coal fineparticles through 120 mesh. ⊡ = distribution of coal fineparticles through 60 mesh. N = nominal size of the sieve aperture in μm.. σ = standard deviation of the sieve aperture distribution.

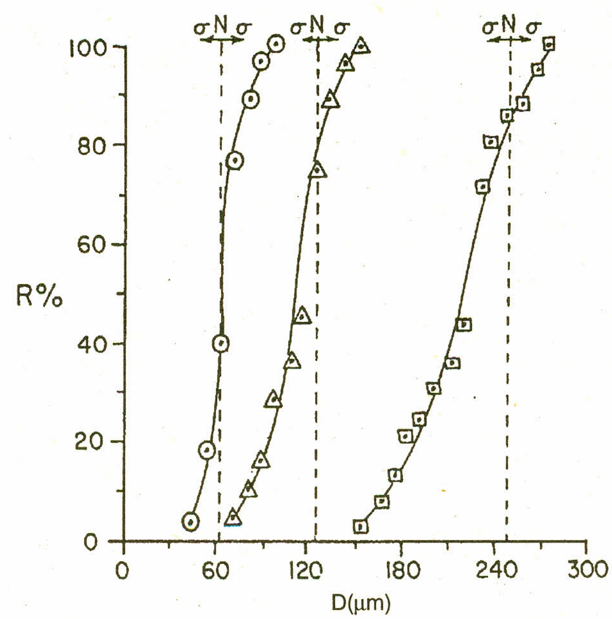

Fig. 7. Size distribution of coal fineparticles passed through 230, 120 and 60 mesh sieves. Inclination of 55° with respect to horizontal plane.

D = size of coal fineparticles in μm. R% = number percentage of coal fineparticles undersize. ⊙ = distribution of coal fineparticles through 230 mesh. Δ = distribution of coal fineparticles through 120 mesh. ⊡= distribution of coal fineparticles through 60 mesh. N = nominal size of the sieve aperture in μm. σ = standard deviation of the sieve aperture distribution.

It is stated in the literature on sieving procedures, that the effective aperture of a sieve is determined by the angle of approach of a powder [1,2]. The data produced in this study does not subtantiate this claim. In fact even at angles of 55 and 65 degrees with respect to the horizontal plane, the effective aperture of the sieve appears to be the same. As the angle of the sieving surface increases, the amount of coal powder passing through the sieve drops off drastically (Fig. 9). At the angle of 65 degrees much less powder passes through the sieve than at the angle of 10 degrees. This fact combined with the consistency of the size distributions passing through the sieve, indicates that as the inclination of the sieve increases, the coal powder starts to flow over the sieve without giving adequate access of the fineparticles to the sieving surface.

Thus it appears that only a boundary layer close to the sieving surface actually permits the fineparticles to pass through the sieve. As the flow of the powder begins to predominate over the accessibility, there is a rapid decrease in the number of fineparticles passing through the sieve. The data strongly suggests that any attempt to develop an inclined plane sieving device should limit the flowing powder down the sieves of different nominal sizes, otherwise as soon as the inclination of the sieve surface commences to exceed a few degrees, movement of the powder over the sieve rather than through the sieve becomes the predominant behavior.

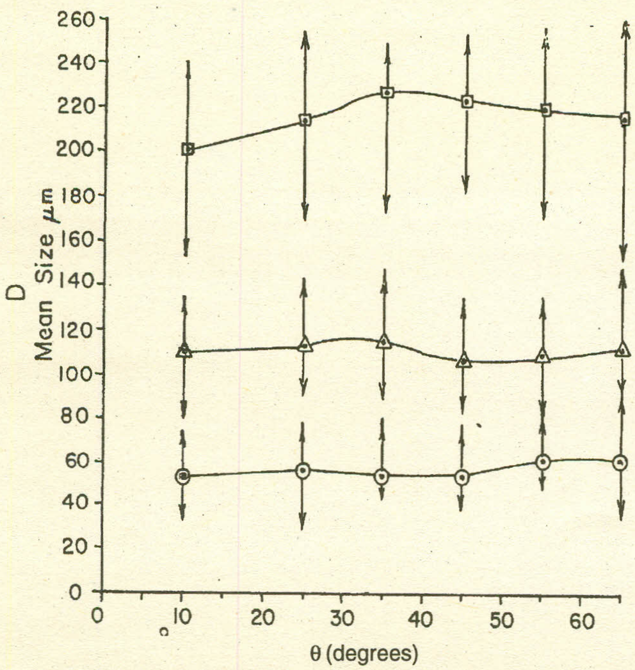

Fig. 8. Mean size of the fractions of coal fineparticles passing through the sieve vs angle of inclinations.

θ =Angle of inclination in degrees. D = Mean size of coal fineparticles undersize. ⇕= 90% and 10% size of the fractions of coal fineparticles in μm. ⊙= Mean of coal fineparticles passed through 230 meash sieve (63μm). Δ = Mean of coal fineparticles pased through 120 mesh sieve (125μm). ⊡ = Mean of coal fineparticles passed through 60 mesh sieve (250μm).

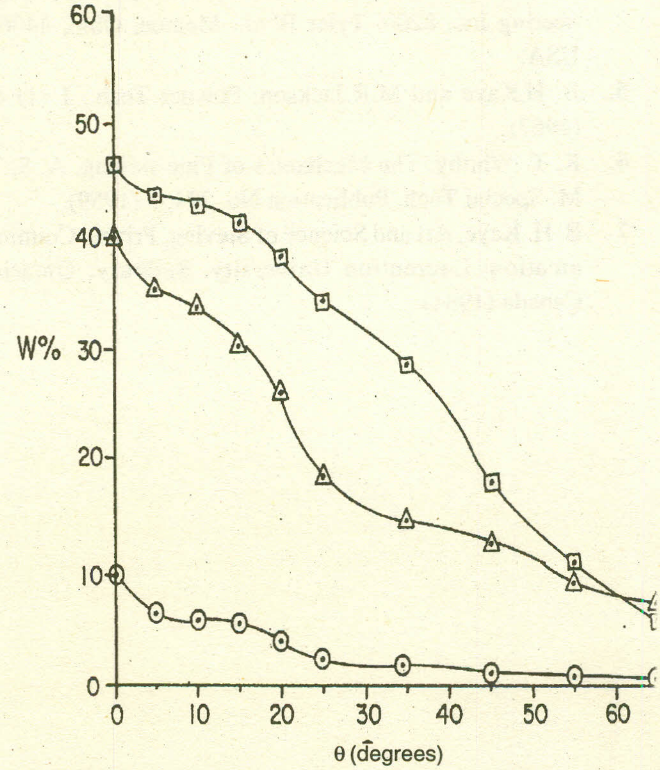

Fig. 9. Effect of angle of inclination of the sieves on the amount of coal fineparticles passing through the sieves.

θ = angle of inclination. W% = weight percentage passing through the sieve. ⊙ = weight percentage passing through 230 sieve. Δ = weight percentage passing through 120 sieve. ⊡= weight percentage passing through 60 sieve.

Conclusion

The experiments reported in this study exhibit that the design of an industrial sieving machine exploiting the kinetics of fineparticles over an inclined plane of the sieve cloths must ensure that a very shallow bed of powder moves over the sieve surface. In such a set up, sieving could be very quickly achieved in relatively short distances (10 cm) on the sieving cloths. This information would be very important in considering automatic sieving procedures.

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References

1. B. H. Kaye, *Direct Characterization of Fineparticles,* (John Wiley & Sons, N.Y. 1985)
2. B. H. Kaye, SORSI and DIGEST, Two Intelligent Machines for Characterizing Fineparticles, in Proceedings of Powder Tech. Conf. Chicago, Illinois. March 10-12, 1977.
3. B. H. Kaye, Powd. Met.,199 (1962).

4. Ro-Tap Sieving Machine from Tyler Combustion Engineering Inc. 8200, Tyler Blvd., Mentoe, Ohio, 44060, USA.
5. B. H.Kaye and M.R.Jackson, Powder Tech., **1** (1) 43 (1967).
6. K. T. Whitby, The Mechanics of Fine sieving, A. S. T. M. Special Tech. Publication No. 234, 3 (1959).
7. B. H. Kaye, Art and Science of Sieving, Private Communication, Laurention University, Sudbury, Ontario, Canada (1984).
8. J. Donato, B. H. Kaye and R. Murphy, Powd. Tech., **2** 49 (1969-70).
9. T. Allen, *Particle Size Measurements* (Chapmann and Hall London, 1978), 5th ed.
10. Image Shearing Microscope from Vickeer's Instruments Company, West Germany (1983-85).
11. Brian H Kaye and M. A. K. Yousuf Zai, Powder and Bulk Engineering, **6,** (2), 29 (1992).
12. M. A. K. Yousuf Zai, Pak. j. sci. ind res., **32,** 5 (1989).