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The estimation of fragmentation in blast muckpiles by means of standard photographs

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SYNOPSIS

The need for the more accurate measurement of blasting results has increased substantially with the proliferation of the types of explosives available to mining operations in South Africa.

The primary object of blasting is the production of broken rock of a specific size distribution. A method for the measurement of size distribution, more popularly known as fragmentation, is being developed at Sishen Iron Ore Mine, and the object of this paper is to describe the method briefly and so encourage an exchange of views on reliable methods.

Once the fragmentation of broken rock can be assessed reliably, meaningful conclusions can be drawn from blasting trials. It will then be possible for equipment productivity to be related to muckpile properties, with the accompanying advantages.

SAMEVATTING

Vandat meer tipes plofstowwe in die plofstofmark verskyn het, het dit belangriker geword om 'n metode te ontwikkel waarmee plofstofresultate objektief vergelyk kan word.

Skietwerk word primêr gedoen om gebreekte rots met 'n hanteerbare grootteverdeling te verkry. 'n Betroubare manier om die grootteverdeling, algemeen bekend as die fragmentasie, te meet, word tans te Sishenmyn ontwikkel. Die doel met hierdie artikel is om die uitgangspunte met die metingstelsel te beskryf, sodat ander kan help bou aan betroubare meettegnieke.

Sodra die fragmentasie van gebreekte rots betroubaar bepaal kan word, sal betekenisvolle gevolgtrekkings na skietwerk gemaak kan word en sal toerustingprestasie gekoppel kan word aan die meetbare eienskappe van frontstapels, wat baie voordelig sal wees.

Introduction

At Iscor's opencast mine at Sishen, the search for an optimal drilling and blasting system to match the loading requirements of the rope shovels is complicated by the diversity of rock types and available explosives. The system currently used in identifying the fragmentation in blast muckpiles arose from a comparison between blasting results from various blasting layouts.

The object of this paper is to describe the system briefly and so encourage an exchange of views on reliable methods. However, before the working method is described, an account is necessary of the basis for defining muckpile fragmentation, which is linked to the Kuz-Ram blasting-fragmentation model.

Kuz-Ram Fragmentation Model

The development of the Kuz-Ram blasting-fragmentation model has been fully described elsewhere[1]. Briefly, it makes use of three algorithms as follows.

(1) The Kuznetsov equation, adapted by AECI for commercial explosives applications, predicts the mean fragment size, $\bar{x}$, from blasting.

(2) An empirical equation using important blasting parameters was developed by Cunningham of AECI, and has been shown by comparison with recorded analyses over several years to give reasonable correlation with blasting fragmentation. This equation, which can be called the uniformity equation, gives a value for n in the Rosin–Rammler equation.

(3) The Rosin–Rammler equation has long been established as approximating the size distribution not only of crushed coal (its original application) but also of rock in blast muckpiles. The equation is as follows:

$$R = 100 \exp - (x/x_c)^n,$$

where R = mass of rock retained on screen size x, %
x_c = characteristic size
n = index of uniformity.

This equation can also be expressed in terms of the mean fragment size, $\bar{x}$, as follows:

$$R = 100 \exp - 0{,}693\ (x/\bar{x})^n.$$

The combination of these three equations for the routine estimation of blasting fragmentation had been put into use by AECI Technical Service Section by 1982. The method has been used fairly extensively and successfully both in South Africa and overseas. Common usage resulted in the adoption of the name Kuz–Ram, which is short for Kuznetsov–Rosin–Rammler.

In summary, the Kuz-Ram model of blasting fragmentation incorporates a number of important blasting parameters to predict the mean fragmentation, $\bar{x}$, and the

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uniformity index, n, for the blast muckpile. These two values enable the overall fragmentation of the muckpile to be estimated.

An exercise conducted at Sishen[2] during 1984 indicated good correlation between blasting results and prediction by the Kuz-Ram model, and this led to the adoption of the model for computerized blast analysis. However, the analysis of actual blasting fragmentation by any known method is time-consuming, and effort was therefore devoted to finding a quick, practical, and reasonably accurate means of determining size distribution in the muckpile.

Fragmentation Analysis by Standard Photographs

Since good correlation with the Rosin-Rammler curve had been established, the following method was developed for the estimation of fragmentation in an unknown muckpile.

Creation of Standardized Rockpiles

As a start, it was estimated that exponent n in the Rosin-Rammler equation would fall between 0,5 (very 'un-uniform') and 2,0 (very uniform). On the assumption of a characteristic size of 10 mm, the required masses of fragments of different sizes were calculated for values of n taken at 0,5 0,75 1,0 1,25 1,5 1,75 and 2,0.

Screened crusher run in the appropriate size ranges, as shown in Table I, was obtained. The sizes were then thoroughly mixed in the correct proportions to form miniature rock piles of known Rosin-Rammler index n. The standardized piles of rock were then arranged in order of ascending n value and exhibited in a suitable shed.

Photographic Technique

Close-up photographs were taken of each rockpile. For scaling purposes, a card with a central blacked area equal to the mean fragment size of that rockpile was included. Figs. 1 to 3 show the clear alteration in texture as uniformity n varies from 0,5 to 2,0. It is also interesting to note that the mean fragment size as indicated on the card is much smaller than might be guessed from visual inspection. This is because larger fragments dominate the view.

The photographs did indeed correlate with the appearance of real-life muckpiles. To provide a basis for the estimation of fragmentation in photographs of real muckpiles, a set of prints was made up for each value of n. Each set consisted of five prints at different magnification, with the black image on the card (the mean fragment size) measuring 1, 2, 3, 4, and 5 mm respectively. Thus, for any value of n between 0,5 and 2,0 (in steps of 0,25), five photographs of increasing scale are available.

A rigid plastic beach ball of 275 mm diameter was obtained for use as a scaling device in the muckpile photographs. Great care was taken with the camera angle and position so that errors of perspective would be avoided and the images of the rocks around the ball would appear similar in size to the rocks in the standard photographs.

Use of the Standardized Photographs

It was immediately apparent that each value of n in a rockpile generates a unique and characteristic 'texture' that does not change with scale.

It was proved by means of numerous 'blind' tests that various mining personnel correctly matched muckpile photographs with the photographs of standard rockpiles. The only slight problem was how to obtain agreement on the correct scale, but this was resolved by careful analysis, which gave rise to the following guidelines.

(i) The best range of photographs to use are those where the mean fragment size is 3 to 5 mm. It is usually possible by eye to match size within 0,3 mm, which represents the minimum percentage error in the larger-scale photographs.

(ii) The muckpile photograph should be masked above and below the position of the scaling object so as to minimize errors of perspective. The use of a telephoto lens on the camera causes fore-shortening of perspective, and thus reduces error from this source.

(iii) While there is an intuitive component of judgement, the sizes of the bigger fragments provide the main basis for selection. The rule is to have not less than three independent opinions as to the correct match.

TABLE I

STANDARDIZED MODEL MUCKPILES

Characteristic size, x_c = 10 mm

Total rock mass = 100 kg

Sieve size, mm	Mass, kg, retained on sieve for values of n: 0,5	0,75	1,0	1,25	1,50	1,75	2,0
0,0	13,2	5,20	2,0	0,70	0,30	0,10	0,0
0,2	13,9	11,10	7,5	4,70	2,80	2,70	1,0
1,0	9,0	9,60	8,6	7,10	5,40	4,00	2,9
2,0	6,1	7,50	7,8	7,40	6,60	5,60	4,7
3,0	8,5	11,50	13,4	14,40	14,60	14,30	13,5
5,0	3,2	4,60	5,8	6,70	7,40	7,90	8,1
6,0	5,2	7,70	10,0	12,10	13,90	15,60	17,0
8,0	8,2	12,30	16,3	20,30	24,20	28,00	31,8
12,5	3,3	4,90	6,3	7,70	8,80	9,70	10,4
15,0	4,2	6,00	7,4	8,30	8,60	8,50	7,8
19,0	4,6	6,10	6,8	6,40	5,40	3,90	2,5
25,0	2,9	3,50	3,2	2,40	1,40	0,60	0,2
30,0	1,0*	1,10	0,9	0,50	0,20	0,10	0,0
32,0	16,7	9,10	4,1	1,40	0,30	0,00	0,0
Total mass, kg	100	100	100	100	100	100	100
Mean fragment size mm	4,8	6,1	6,9	7,5	7,8	8,1	8,3

The mass per size range indicated in the table is obtained by means of the Rosin-Rammler equation

**Example:* What mass fraction (R) should be retained on the 32 mm sieve if n = 0,5?

For 30 mm sieve, $R(30) = 100 \exp -(30/10)^{0,5} = 17,7\%$.

For 32 mm sieve, $R(32) = 100 \exp -(32/10)^{0,5} = 16,7\%$.

Thus, the mass retained between 30 mm and 32 mm sieves $= 17,7 - 16,7 = 1\%$ or 1 kg.

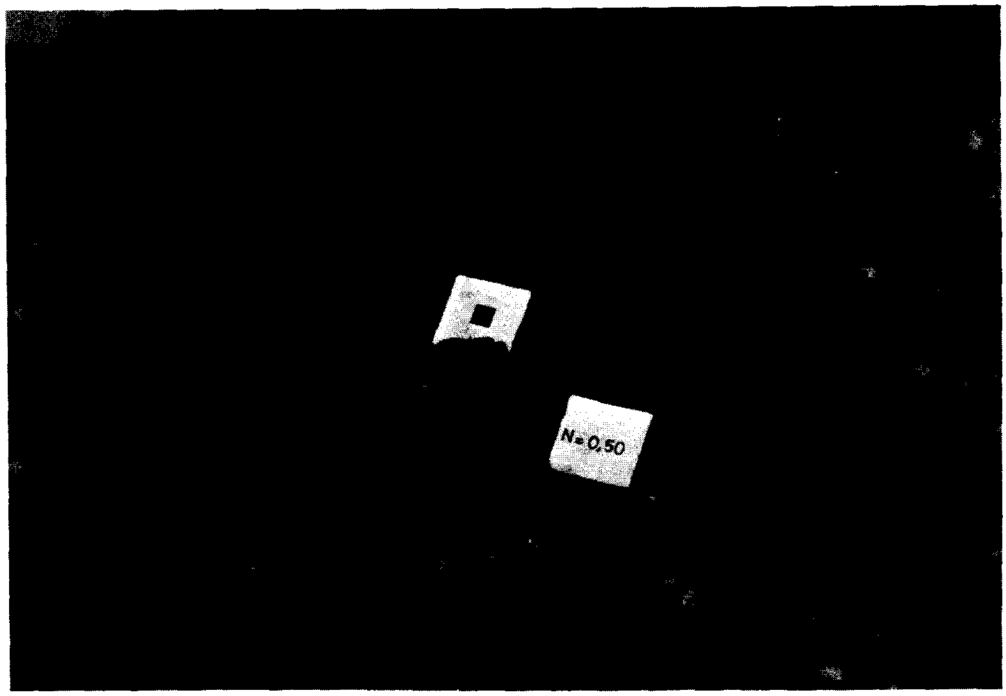


Fig. 1—Fragmentation of low uniformity

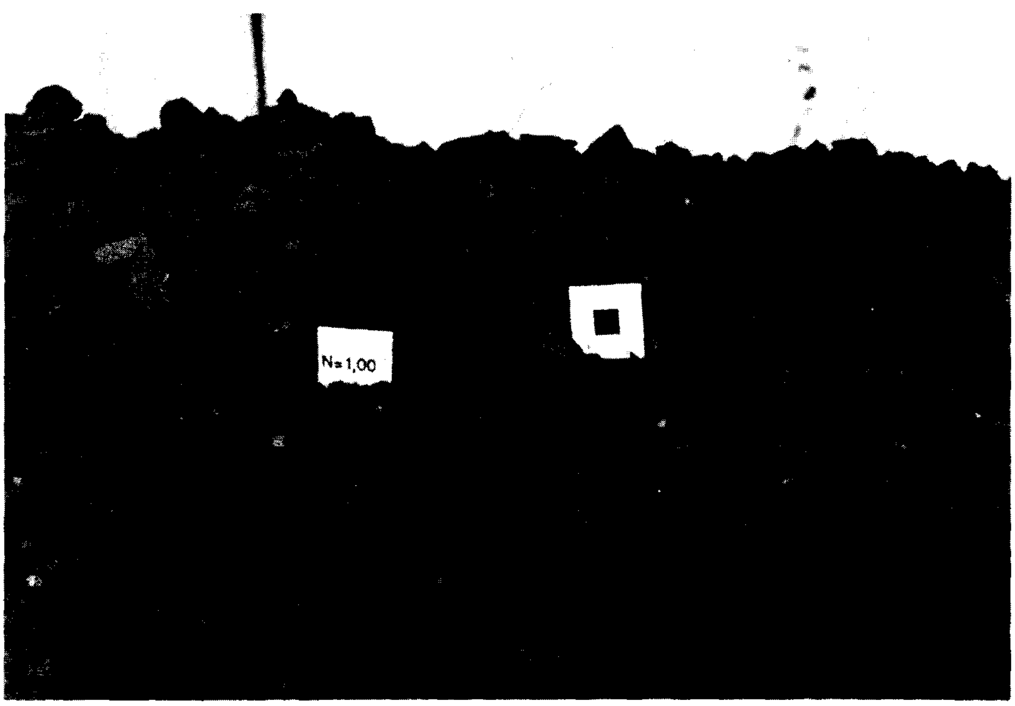


Fig. 2—Fragmentation of medium uniformity

The following worked example shows how a muckpile photograph can be analysed by this technique. Fig. 4 shows a photograph of a muckpile identified as having an n equal to 1,25, together with standardized photographs with mean fragment image size equal to 4 and 5. Opinions canvassed agreed that the best match was 4 mm.

The size of the ball image on the muckpile photograph is 8,5 mm, which corresponds to 275 mm in real life. Scaling is therefore in the ratio of 275 : 8,5, or 32,35 : 1. The mean fragment image size was identified as 4,0 mm. Thus, the actual mean fragment size is (4,0 × 32,35 mm) = 130 mm. As exponent n is 1,25, the complete fragmentation curve is $R = 100 \exp - 0{,}693\,(x/13)^{1{,}25}$. This is plotted in Fig. 5.

Discussion

The accuracy of this method is related largely to the scale of the objects in the photographs, larger scales yielding more accurate estimations. The disadvantage of a large-scale photograph is that less area of the muckpile can be covered, so that more photographs are required. A compromise has therefore to be made between scale and overall accuracy, and this must be balanced against

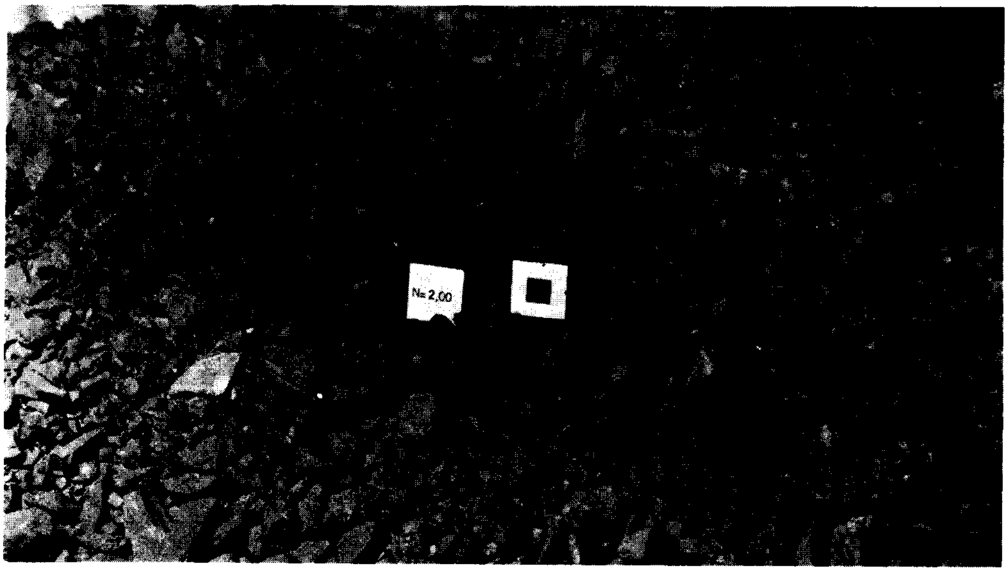


Fig. 3—Fragmentation of high uninformity

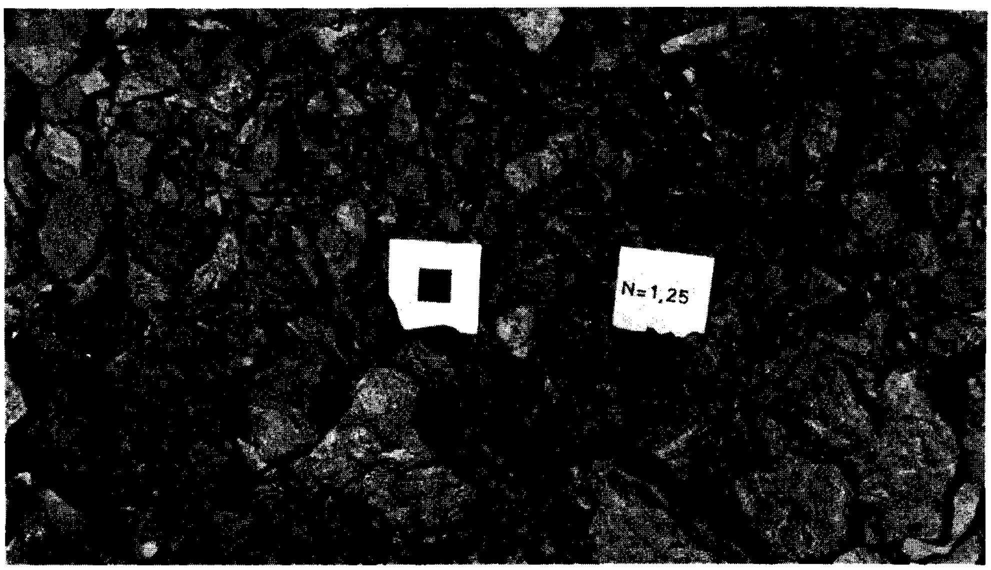


Fig. 4—Comparison of a muckpile with standardized photographs

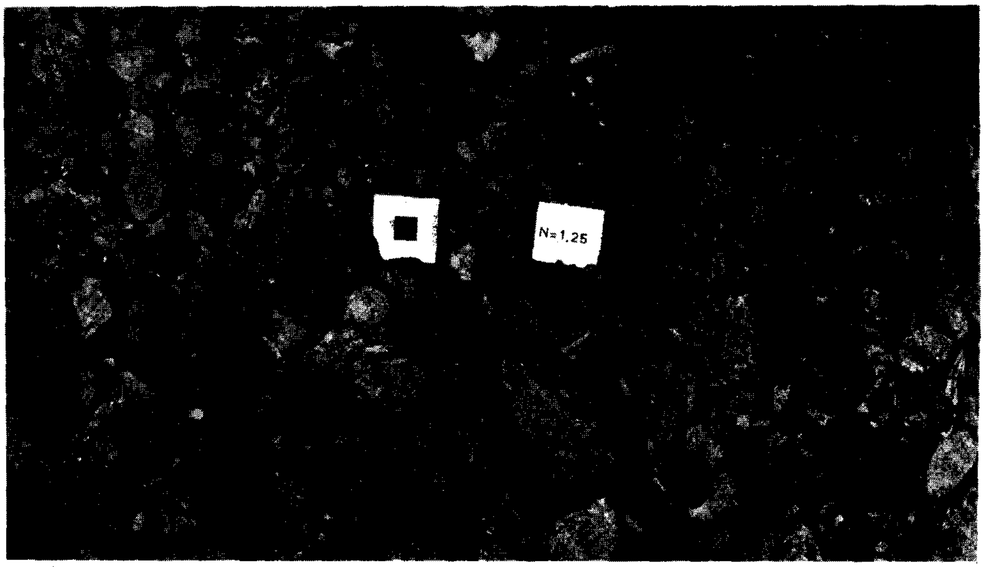
(a) $\bar{x}$ = 4 mm

Fig. 4—Comparison of a muckpile with standardized photographs

(b) Ball diameter = 275 mm
Image diameter = 8,5 mm

Fig. 4—Comparison of a muckpile with standardized photographs

(c) $\bar{x}$ = 5 mm



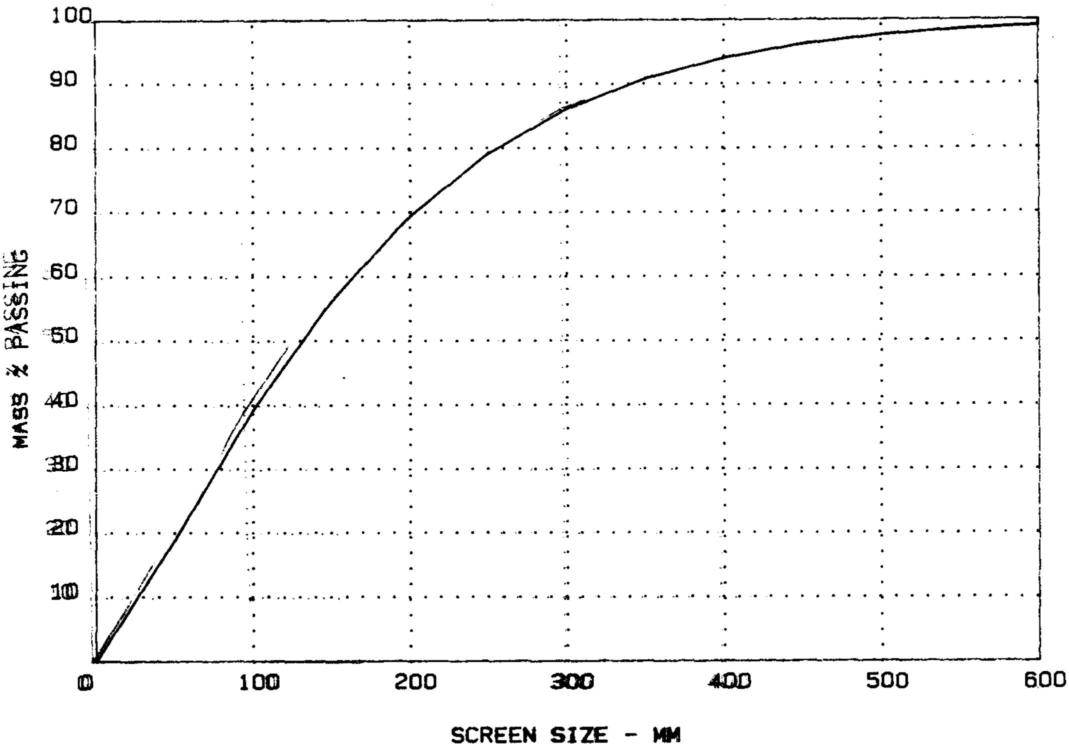


Fig. 5—The fragmentation curve for the worked example

the importance attached to the final analysis.

Oversize fragments normally constitute a very small percentage of the overall rockpile, and small errors in estimation can therefore represent large differences in the numbers of oversize rocks. For example, 1 per cent oversize in a 200 kt blast is 2 kt, while 1,5 per cent oversize is 3 kt. Statistically, there is very little difference, but the mine encounters 50 per cent more troublesome boulders. In addition, oversize boulders, once greater than the minimum, tend to be seen as units, irrespective of size: one 1,2 m boulder massing 6 t is not seen as being very different in handling difficulty from a 2,0 m boulder massing 28 t.

For these reasons, the estimation of oversize by this or any other method can be misleading. The method has greatest accuracy in the region of mean fragment size, which is a good indicator of the overall ease of digging.

For the following reasons, the larger the mean fragment size, the greater the cost of digging a muckpile:

(a) the tendency of large particles to cause bridging between the sides of the power-shovel bucket, reducing the capacity and increasing the crowding force;
(b) greater wear and tear from the sliding of the bucket between and under heavier fragments.

It is a fairly well-established mining principle that, for an end-constrained fractured beam to collapse (e.g. a hangingwall stratum), about seven perpendicular fractures are required. The fewer the fractures, the greater the stiffness of the rock between the confined ends and the less likely is the beam to fall. The flow of particles through an aperture is also much impeded if the particles exceed one-seventh of the aperture in diameter.

In the same way, a loading bucket should be wide enough relative to the mean fragment size to permit lateral and longitudinal flexing to the particle sample being loaded, facilitating low-friction entry into the bucket. Thus, as a rule-of-thumb, a 2,1 m wide bucket should not be used where the mean particle size exceeds (2,1/7) = 0,3 m. Further work is planned to validate this principle.

Conclusion

The method described above for the rapid analysis of muckpile fragmentation is believed to be an important tool in the assessment of blasting results. Until this kind of measurement can be made, it is difficult to draw meaningful conclusions from blasting trials, or relate equipment productivity to muckpile properties.

From now on, the emphasis at Sishen will be to relate the information obtained by photo-analysis of portions of the muckpiles during loading to the values predicted by the Kuz–Ram model. Once the reliability of the model has been established, a database relating equipment performance (and hence economic implications) to specific fragmentation indexes, will be built. Only then will it be possible for fragmentation objectives to be set scientifically and blasting trials to be meaningfully compared.

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Hydrocyclones

The 3rd International Conference on Hydrocyclones will be held in Oxford (England) from 30th September to 2nd October, 1987.

Hydrocyclones are widely used in many industries to separate the end product from undesirable impurities over a range of combinations from solid–solid to gas–liquid. However, the fluid mechanics of hydrocyclones is not well understood, and both users and system designers have tended to use a pragmatic approach. For example, in the mining industry, because design criteria have not been established to cover the complete range of particles to be removed, more expensive or wasteful methods may be preferred. To obtain the maximum high-quality product, particle size and the possibility of using hydrocyclones in series, and prescreening may have to be considered. Other industries, such as paper, food, chemical, and pharmaceutical manufacturers, could also benefit from a close study of the fluid mechanics of hydrocyclones as applied to their own requirements.

BHRA believes that this meeting will enable operators, contractors, and suppliers to discuss the theory, design, and practical application of these low-cost devices across industry with a view to improving their efficiency and use.

It is proposed to organize a Hydrocyclones Course on the two days preceding the Conference. Further details will be made available at a later date.

The Conference is expected to cover all aspects of the theory, design, development, and practical applications of hydrocyclones, including the area of control, wear, and system maintenance.

Papers describing the use of hydrocyclones in process industries such as chemical, mineral, petroleum, pulp and paper, food, pharmaceutical, and textile are invited. Contributions concerning industrial waste-water treatment, metal working, and power generation will also be considered. Offers of papers detailing the use of hydrocyclones for density separations and utilizing dense media will be particularly welcome.

Authors should please note the following.

- In all cases work must be original and should not have been published or offered for publication elsewhere.
- Papers must be submitted and presented in English.
- Papers accepted for presentation will be published by BHRA in a bound volume of papers and where possible issued to delegates before the meeting. The volumes will be made available for sale at a later date.
- Authors are expected to present their papers and to attend the meeting as delegates, but will be entitled to a substantial reduction in the conference fee.

Enquiries should be addressed to

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