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The open-circuit production of material finer than 75 µm in open-circuit mills

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SYNOPSIS

The production of material finer than 75 µm in a number of open-circuit mills was investigated. The mills ranged from laboratory rod and ball mills treating a variety of ores to large industrial rod mills treating gold and copper ores.

It was shown that the dependence on feed rate of the production of material finer than 75 µm can be accurately described by a simple formula that was derived in previous work. In some of the systems reviewed, it proved possible to assess the feed rate of ore to the mill at which the rate of production of material finer than 75 µm can be maximized.

SAMEVATTING

Die produksie van materiaal fyner as 75 µm deur 'n aantal oopkringmeule is ondersoek. Die meule het gewissel van laboratoriumstaaf- en -balmeule wat 'n verskeidenheid ertse behandel, tot groot industriële staafmeule wat goud- en kopererts behandel.

Daar is getoon dat die afhanklikheid van die produksie van materiaal fyner as 75 µm van die toevoertempo na die verskillende maalstelsels noukeurig beskryf kan word deur 'n eenvoudige formule wat in vorige werk afgelei is. Dit was in sommige van die stelsels wat ondersoek is, moontlik om die toevoertempo van erts na die meul waarby die produksietempo van materiaal fyner as 75µm gemaksimeer kan word, te raam.

Introduction

The production of material finer than 75 µm is of interest in diverse fields of the mineral-processing industry. The present work suggests that, in the case of open-circuit milling, the mass fraction of the product finer than 75 µm, $P_{75}(F)$, expressed as a function of the feed rate of ore to an open-circuit mill, F, is given by

$$P_{75}(F) = \frac{1 + \alpha F}{1 + \beta F} \qquad 1$$

where α and β are constants with α less than β.

The formula in Equation 1, which is thought to be valid when the size distribution of the feed and the water-to-solids ratio in the mineral pulp remain constant, suggests that the fraction $P_{75}(F)$ tends to unity as F tends to zero. Hence, all of the product will be finer than 75 µm at very low feed rates, and this fraction will decrease as the feed rate of ore to the mill increases.

A formula that is essentially of the form of Equation 1 was derived in previous work[1,2], which considered the dependence of the product-size distribution on the feed rate when quartz gravel was milled in a pilot plant at Mintek. The formula was in excellent agreement with the results obtained when the mill was operated with a wide variety of grinding media: steel balls of various sizes, cones, cylpebs, and pebbles of various sizes. The results suggested that, for the given milling system (0,6 by 0,6 m mill, 0,72 of critical speed, wet milling at 72 per cent solids), the formula would be valid for any grinding medium irrespective of the shape or composition of the grinding elements.

The aim of the present work was to determine whether Equation 1 would also be applicable to the results derived from other open-circuit mills. Data were obtained from the literature for a number of laboratory mills, and tests were carried out on a large industrial rod mill at East Driefontein Gold Mine.

Rod Milling at East Driefontein Gold Mine

The No. 1 milling unit at East Driefontein, which is under multivariable control[3], consists of a primary rod mill in open circuit followed by two pebble mills. The latter are in parallel and are operated in closed circuit with two hydrocyclones. The rod mill measures 2,74 m by 3,66 m, and is operated at 19 r/min (about 72 per cent of the critical speed). It is fitted with manganese-steel lifter bars that are bolted onto the crests of wave-type liner blocks. The mill is charged with 90 mm steel rods to about 40 per cent of its internal volume, and is replenished at regular intervals with the appropriate number of rods. The consumption of steel as grinding rods is about 0,5 kg per tonne milled.

Although the tonnage is variable since the rod-mill feed rate is one of the control actions of the multivariable control system, the milling rate is usually between 50 and 70 t/h. The crushed feed has a moisture content of about 1 per cent, and water is added to bring the total moisture content of the pulp up to 28 per cent by mass. The moisture is strictly controlled to minimize rod tangles, which are liable to occur when the solids content of the feed is too high.

The minimum rate at which ore can be fed to the mill is about 40 t/h. At lower feed rates, the cushioning effect of

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coarse particles is reduced, thus giving rise to damage of the liner blocks and loosening of the liner bolts. The maximum feed rate is limited to about 80 t/h since a very coarse discharge is obtained at such high tonnages. In the work reported here, the circuit was operated manually at various feed rates between 47 and 75 t/h for short periods (1 or 2 hours) during which the mill product was sampled with standard sample cutters. The samples were screened at 1700 μm, and were then dried and screened at 250 μm, 150 μm, and 75 μm according to standard plant procedures. The fractions finer than 75 μm obtained at twenty different feed rates of ore to the mill are shown in Table I.

Table I

INDUSTRIAL ROD MILLING OF WITWATERSRAND QUARTZITE

Size analysis of feed

Screen	19 mm	13 mm	6 mm	75 mm	< 75 mm
% retained	7,3	28,4	37,6	24,8	1,9

Feed rate t/h	Percentage <75 μm
71,5	9,7
73,6	15,2
47,4	18,9
47,0	23,5
56,4	18,3
51,9	22,1
54,6	18,5
50,3	22,3
52,9	18,9
55,4	12,5
59,7	15,9
74,7	15,4
63,6	15,1
59,5	15,6
70,2	13,3
65,7	16,0
64,5	15,1
46,8	19,5
59,7	12,9
62,3	14,7

Results

Several papers[1, 2, 4–8] have reported the product-size distributions at three or more feed rates of ore to open-circuit laboratory mills. Most of those results were obtained in the course of experiments to confirm that the population-balance model, based on breakage and selection functions, is capable of predicting the steady-state product-size distribution of open-circuit mills. Some of the papers reported numerical data, but the majority showed only graphs of the log of the fraction finer than size x (i.e. log P_x) versus the log of the indicated size (i.e. log x). In the latter cases, the numerical values of $P_{75}(F)$ were determined from the graphs by measurement of the co-ordinates of plotted data points with a travelling microscope.

The values thus obtained for the fraction of material finer than 75 μm as a function of the feed rate of ore to seven pilot-plant systems are shown as data points in Fig. 1. Standard non-linear least-squares methods were used to fit Equation 1 to these data, the values of the parameters α and β thus obtained being given in Table II. These values were then used to create the continuous curves shown in Fig. 1.

The data from industrial mills were treated in a similar manner. Fig. 2 shows data[8] from a 2,66 m by 3,66 m rod mill when treating a copper–lead–zinc ore at Mount Isa Mines, as well as those from East Driefontein. Although the data from East Driefontein show considerable scatter, they exhibit a clear trend.

Discussion

The continuous curves shown in Figs. 1 and 2 demonstrate that the simple formula given in Equation 1 provides a remarkably accurate description of the results obtained from nine open-circuit mills of various sizes in which different ores were milled with a variety of grinding media. The mills range from small laboratory ball mills to large industrial rod mills. The values of the parameters α and β on which the various curves are based are given in Table II. Table II shows for the majority of the systems that α is negative. In these cases, the applicability of Equation 1 is restricted to the interval $0 < F < |\alpha|^{-1}$, which experience has shown always embraces the complete range of feed rates of ore that may be used in practice with any given mill.

The significance of the sign of α is illustrated in Fig. 3, which shows graphs of the rate of production of material finer than 75 μm by the two industrial rod mills. The value of this quantity is given by

$$\Pi_{75} = F\frac{1 + \alpha F}{1 + \beta F}. \quad \text{.............................} \quad 2$$

If α is negative, as it was for the mills operated by Heyes *et al.*[5], Howat and Vermeulen[1,2], Austin and Klimpel[7], and the rod mill at East Driefontein, then Equation 2 predicts that the rate of production of minus 75 μm material will pass through a maximum. In this event it is easily shown that the rate of production can be maximized at a feed rate, F_{max}, given by

$$F_{max} = \beta^{-1}\left\{(1 - \beta/\alpha)^{1/2} - 1\right\}. \quad \text{.............} \quad 3$$

Thus, for the rod mill at East Driefontein, the value of F_{max}, as shown in Fig. 3, is about 49,5 t/h, i.e. well within the operating range of the mill. At this feed rate, the production of material finer than 75 μm is about 235 t/d—a value that cannot be exceeded by an increase in the feed rate of ore of the given size distribution to this mill.

On the other hand, for the rod mill at Mount Isa Mines[8] and the ball mills operated by Kinneberg and Herbst[4] and Reddy *et al.*[6], the values of α are positive. In those cases, the rate of production of minus 75μm material is a mono-

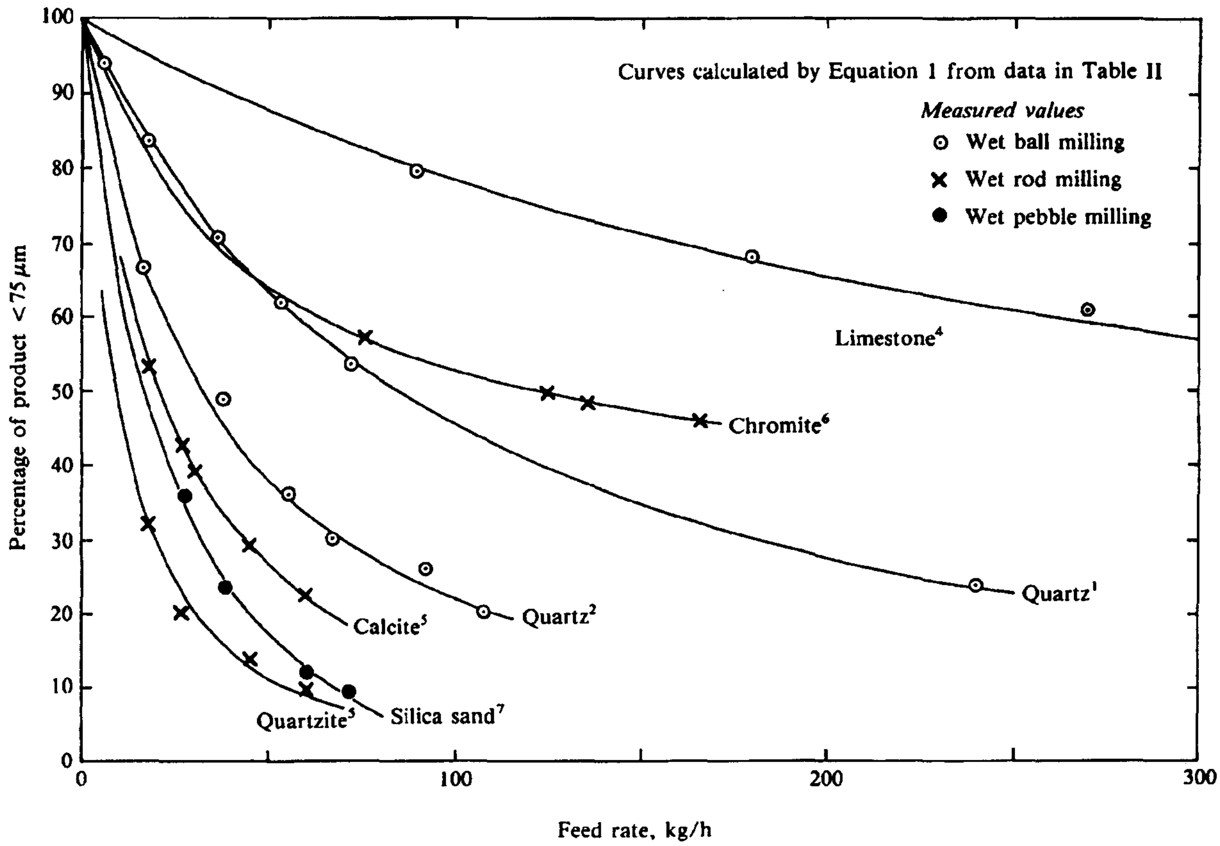

Fig. 1—The production of material finer than 75 µm in several laboratory milling systems

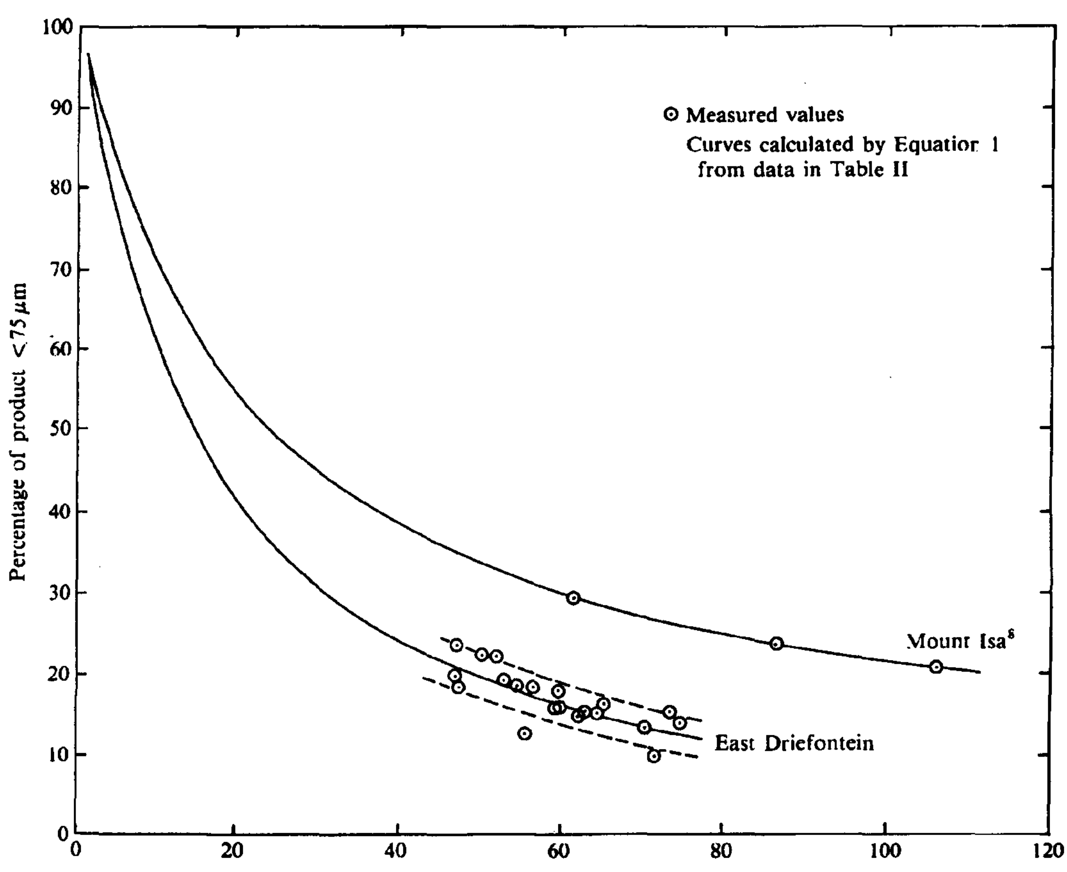

Fig. 2—The production of material finer than 75 µm by two industrial rod mills

Table II

VALUES OF THE PARAMETERS ASSOCIATED WITH THE PRODUCTION OF MINUS 75 μm MATERIAL IN OPEN-CIRCUIT MILLS

Milling system	Feed	α (kg/h)$^{-1}$	β (kg/h)$^{-1}$	F_{max}† kg/h
Wet ball milling[4]	Limestone	0,510 x 10^{-3}	3,426 x 10^{-3}	–
Wet rod milling[5]	Calcite	-3,584 x 10^{-3}	41,967 x 10^{-3}	61,1
Wet rod milling[5]	Quartz	-5,401 x 10^{-3}	105,2 x 10^{-3}	33,5
Wet ball milling[1]	Quartz	-0,773 x 10^{-3}	10,285 x 10^{-3}	270,5
Wet pebble milling[2]	Quartz	-7,71 x 10^{-3}	27,680 x 10^{-3}	113,6
Wet ball milling[6]	Chromium ore	6,64 x 10^{-3}	21,57 x 10^{-3}	–
Wet ball milling[7]	Silica sand	-9,118 x 10^{-3}	42,375 x 10^{-3}	32,5
Industrial rod milling[8]	Cu–Pb–Zn ore	2,303 x 10^{-6}	46,870 x 10^{-6}	–
Industrial rod milling*	Quartzite	-3,989 x 10^{-6}	61,613 x 10^{-6}	49 600

* Present investigation

† Feed rate at which the rate of production of minus 75 μm material passes through a maximum

tonic, although sublinearly increasing, function of the feed rate, as shown, for example, by the curve for Mount Isa Mines in Fig. 3.

Conclusions

(1) A simple formula that was derived in previous work to give a quantitative description of the production of material finer than 75 μm by an open-circuit laboratory ball mill implied that, under certain conditions, the rate of production of material finer than 75 μm in open-circuit milling could pass through a maximum. The present study showed that the given formula provides an accurate description of the production of material finer than 75 μm in all the open-circuit mills investigated so far.

(2) It was confirmed, in a large industrial rod mill at East Driefontein Gold Mine, that it is possible to maximize the rate of production of material finer than 75 μm by means of adjustments to the feed rate of ore.

(3) The results of the present work, by showing that the production of fine material in both small laboratory and large industrial mills is accurately described by the same formula, provide some support for the validity of scale-up procedures in milling.

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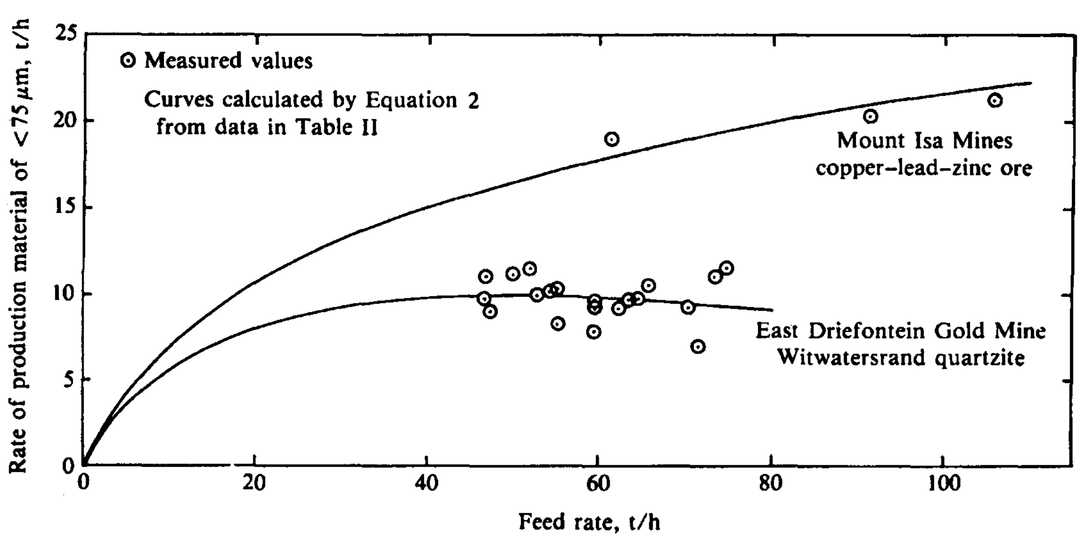

Fig. 3—The rate of production of material finer than 75 μm by two industrial rod mills

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EPPIC Awards for 1992

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Technical note

Major Savings in Grinding

A report released by Grinding Process Development Co. Ltd of Montreal describes a programme of plant experimentation with different types of grinding media, which took place over five years. With the aid of 'functional performance analysis' of ball milling, an innovative method by which the efficiency of the ball-mill environment can be measured in any given plant situation, grinding efficiency was improved by approximately 20 per cent. As a result, the overall operating cost of ball milling was reduced by 14 per cent.

The study was sponsored jointly by the operating company and the manufacturer of the grinding media, who also co-authored the report. It was presented at the Copper 91 International Symposium, which was held in conjunction with the 30th Annual Conference of Metallurgists of the Canadian Institute of Mining, Metallurgy and Petroleum in Ottawa, Canada, from 18th to 20th August, 1991.

The report summarizes the development of the functional performance equation for closed-circuit ball milling as follows:

'Circuit production rate of new product size material = Total mill power draw x Classification system efficiency x Ore laboratory grinding rate x Grinding environment efficiency'.

This equation reveals that the output of a ball-mill circuit depends on the four factors listed, each of which can be readily determined from a plant sampling survey. By successive changes to the type of grinding media added to the ball mill, the 'grinding environment efficiency' was successfully increased over the lengthy programme of plant testing. Overall improvements in circuit efficiency were also verified by traditional Bond work-index techniques.

To obtain a copy of this report, or for further information on this topic, address enquiries to

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