A review of real-time particle size analysers

A. L. HINDE,* B.Sc., A.R.C.S., D.I.C., Ph.D.

SYNOPSIS

The physical principles of different sizing techniques are critically examined in order to evaluate the suitability of the techniques for real-time particle size assessment. Examples of both successful and unsuccessful attempts at producing an acceptable real-time sizer are described in order to delineate the difficulties involved in making rapid and accurate size measurements. Only two of the examples described have proved to be suitable for on-line particle size monitoring, namely the "Mintek/RSM On-stream Slurry Sizer" manufactured by Cartner Group, Ltd., and the "PSM System 100" made by Autometrics Co. Both these commercial systems are capable of assessing particle size with an accuracy comparable with that obtained by routine sieving and weighing. The "PSM System 100" has been used successfully for automatic control of grinding circuits. Economic benefits derived from this system, operating under rigorous plant conditions for several months, have proved that real-time size analysers are of significant value to the mining and metallurgical industry.

SINOPSIS

Die fisiese beginsels van verskillende grootte bepalings tegniek word krities ondersoek om sodoende die geskiktheid van die tegnieke vir werklike tyd korrelgrootte waardasies vas te stel. Voorbeelde van beide suksesvolle en onsuksesvolle pogings om 'n aanvaarbare werklike tyd groottemetingsinstrument te produseer word beskrywe om sodoende die moeilikhede uit te beeld wat gepaard gaan met vinnige en akkurate grootte bepalings. Slegs twee van die voorbeelde beskrywe was geskik gevind vir op-lyn korrelgrootte waarneming, naamlik die „Mintek/RSM On Stream Slurry Sizer" vervaardig deur Cartner Group, Ltd., en die „PSM System 100" vervaardig deur Autometrics Co. Beide hierdie kommersiële sisteme is instaat om korrelgrootte weer te gee met 'n akkuraatheid wat vergelyk kan word met die verkry deur roetine siffing en weging. Die „PSM System 100" is alreeds suksesvol aangewend vir outomatiese kontrole van meule kringlope. Ekonomiese voordele voortvloeiende uit hierdie sisteem in werking in aanlegte oor verskeie maande onder strawwe toestande het bewys dat werklike tyd grootte analise van betekenisvolle waarde is vir die myn en metallurgiese industrieë.

INTRODUCTION

In the mining and metallurgical industry, particle size effects can influence the economics of extracting metals from their ore-bodies. In order to liberate the valuable mineral component it is necessary to grind the ore to a fine size. The desirable size distribution of the product after comminution is determined by such factors as the value of the metal, the cost of grinding, and the kinetic response of milled product to chemical and physical processes. The response of the process equipment to variations in particle size is also an important parameter. The exact effect of particle size on these factors and on the overall efficiency of the extraction process is not well understood. Therefore, it is generally believed that a rapid and accurate method of sizing might prove to be a useful diagnostic tool in studies of the relationship between the numerous parameters involved in the extraction process.

Of particular importance is the need for rapid size analysis to control milling circuits. Surges in the circuits lead to fluctuations in particle size and result in losses in productivity and profitability.

A study of the literature[1, 2] on the subject has shown that research directed towards the development of real-time size analysers for the industry has been pursued for at least a decade. However, little success has been achieved and few real-time sizers have been developed to the stage at which commercial manufacture was warranted. Although many rapid sizing methods can give results sensitive to particle size variations, the specifications of acceptability are stringent in that methods must have an accuracy as reliable as that of the routine sieving analyses normally practised by the industry. This criterion for accuracy is difficult to achieve. In order to delineate these difficulties, the physical principles of different sizing methods have been examined critically. The principles upon which the methods are based are:

(a) measurement of slurry viscosity.
(b) sedimentation and elutriation techniques.
(c) electro-optical scanning.
(d) optical grating.
(e) light diffraction.
(f) sieving techniques.
(g) size segregation in a helical tube.
(h) ultrasonic attenuation.

Although the list is by no means complete it is thought that it contains examples of most of the physical principles which numerous potential real-time size analysers have utilised or attempted to utilise.

SIZE ANALYSIS BY MEASUREMENT OF SLURRY VISCOSITY

It is well known that the rheological properties of very dilute slurries are dependent upon the volume concentration of the solids present. The relative viscosities of such dilute suspensions can be represented by the familiar Einstein equation:

$$\eta_r = 1 + kC$$

where η_r = relative viscosity
k = shape factor constant
C = fraction by volume of solids

It is generally believed that particle size has little influence on the rheological properties of very dilute suspensions. However, as the concentration of solids increases, electro-viscous and other interparticle effects become significant. Although a satisfactory theory has

*Research Organisation, Chamber of Mines of South Africa.

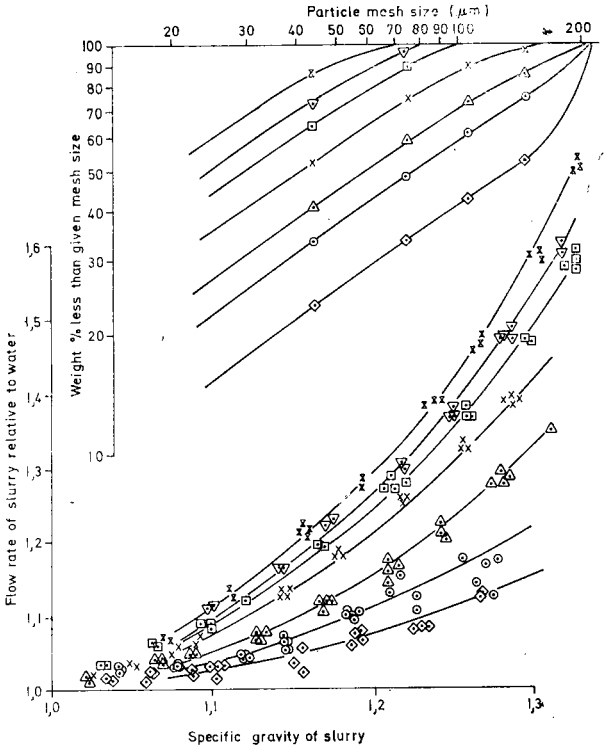

Fig. 1—Rheological properties of gold ore slurries

yet to be developed, it has been demonstrated[3] that as a consequence of these effects the fluidity of suspensions decreases as particle size decreases.

The influence of particle size distributions on the rheological properties of gold ore slurries is shown in Fig. 1. These results were obtained from measurements with a capillary viscometer. It will be seen that changes in apparent viscosity of a slurry are very insensitive to size variations, even at high solids concentrations. This lack of sensitivity is a major disadvantage in size analysis since extraneous factors, unless controlled rigidly, can produce apparent viscosity changes comparable with those which result from expected changes in particle size. For example, large discrepancies can arise because of lack of homogeneity of the slurry, variations in temperature, and the presence of trace amounts of chemical reagents.

In spite of the inherent difficulties of the method Brown[4] attempted to show that monitoring of grinding circuits by measurement of changes in viscosity could be a feasible proposition. He suggested the use of a density-sensitive gauge in close proximity to the viscosity probe. The resulting signals would then be processed to yield a signal, dependent on average particle size, which could be used to control equipment. Little success was achieved since accurate and meaningful results could not be obtained. Both theory and preliminary attempts at practice thus make it clear that the observation of changes of viscosity for monitoring particle size effects is not likely to yield great success.

METHODS OF SIZING BY SEDIMENTATION AND ELUTRIATION

Sedimentation and elutriation methods are based on the property that solid particles will settle in a viscous medium, such as water, at a velocity related to particle size. The method is generally used for particles smaller than standard sieve mesh sizes (less than 44 μm) since the settling velocity of such particles can easily be related to particle size according to Stokes' law:

$$V=\frac{(\rho_s-\rho_w)d^2g}{18\eta}$$

where V = settling velocity
d = particle diameter
g = acceleration of gravity
η = viscosity of suspending medium
ρ_s = density of solids
ρ_w = density of suspending medium

Although larger particles do not obey this simple law, their settling velocities can nevertheless be calculated or determined empirically. The methods are therefore capable in principle of coping with particles ranging in size from a few micrometres to a few millimetres. It is important to note from the Stokes' law equation that size is determined by the viscosity of the suspending medium which in turn is sensitive to changes in temperature. Temperature control is therefore a necessary condition for accurate size analysis, but it presents problems in rapid size assessment. It is important to note that size is also determined by the density of the solid phase. In many situations ore-bodies can contain several gangue minerals of different densities. Variations in the relative proportions of these minerals can lead to changes in average density and thus give inaccurate results. A further disadvantage is that the equation holds for only very dilute suspensions, so that any real-time analyser must have available to it very large volumes of clear water. Finally, it should be noted that the equation is valid only for spheres, and that the particle sizes found by sedimentation methods are therefore "spherical equivalent" sizes. For roughly cubical particles, it is not too difficult to relate sedimentation or elutriation "sizes" to sieve sizes, but for plate or rod-shaped particles the sedimentation method may yield particle sizes which differ significantly from sizes estimated by screening.

The disadvantage of sedimentation methods for determining cumulative size distributions is that they cannot be used on-line, and analysis must be done off-line with batch samples. A further disadvantage of sedimentation methods is that considerable time is normally needed to perform a size analysis. A sedimentation instrument is available commercially[5] (Micromeritics Instrument Co.) by which the time for size assessment has been shortened considerably. This instrument determines, by means of a finely collimated beam of X-rays, the concentration of particles remaining in suspension at various sedimentation depths as a function of time. To minimise the time of analysis the position of the sedimentation cell is changed continuously so that the effective sedimentation depth is inversely proportional to elapsed time.

Elutriation methods are attractive in that they make on-line size assessment possible. The concept behind such methods is that a stream of particles is fed into an elutriation column and separated into two streams at a

certain cut-off size. The cumulative oversize fraction is related to the mass flow rates in the feed and overflow. Because of the viscosity of the water flowing in the elutriation column a parabolic velocity front exists. This prevents the attainment of a sharp cut-point. The effect of the uneven cut is the removal of coarse above the theoretical cut-point while leaving behind some of the fines. Thus, although the separate fractions are not accurately sized, the cumulative mass fraction is often reasonably close to the correct value. A similar compensating effect also applies if the density of individual particles differs from the mean solids density. In spite of the apparent simplicity of the elutriation technique its application to real-time size analysis has received little attention. Some of the problems likely to arise in application of the method stem from the need for careful sample preparation. It is important to ensure that the particles are suitably dispersed prior to their entering the elutriation column. With water as the suspending medium it may be necessary to prevent agglomeration of fines by adding an electrolyte or by use of ultrasonics. In order to prevent interparticle effects inside the elutriation column it is imperative that the solids concentration should be very low (at the most 1 per cent by weight). For an on-line size analyser based on this method such high dilutions give rise to problems of statistics which make it difficult to monitor representative samples of the process stream.

Nakajima, Gotoh and Tanaka[6] describe an on-line particle size analyser based on an elutriation technique using air rather than water as the suspending medium. The instrument was capable of automatically recording cumulative size distributions which agreed with sieving results to within about 10 per cent. It is understood that the South African Atomic Energy Board is also attempting to develop an analyser based on elutriation.

SIZING BY ELECTRO-OPTICAL SCANNING

Electro-optical scanning techniques involve automatic counting and sizing of individual particles. The method has enjoyed considerable success for particles restricted to a narrow size range (this method is utilised by the "Coulter Counter"). Unfortunately, crushed or finely-ground brittle material often has particle sizes spanning several orders of magnitude; and the number of smaller particles greatly exceeds that of larger particles. Severe instrumental problems arise when the closely-spaced small particles must be recognised by receivers as separate entities.

An example of an attempt at developing the method for mineral ore slurries has been described by Ricci and Cooper[7]. In their particle size analyser an upward-flowing slurry stream is scanned by a focussed horizontal light beam derived from a helium-neon laser. Scanning is achieved by reflecting the light beam off the surface of an oscillating mirror. As the light beam traverses the sample its passage is interrupted by the presence of the particles in the stream. The time and frequency of interception are related to the particle size distribution. These interruptions can be determined using a fast photodiode, and with sophisticated electronics it is possible to process the signals from the photodiode to yield the particle size distribution.

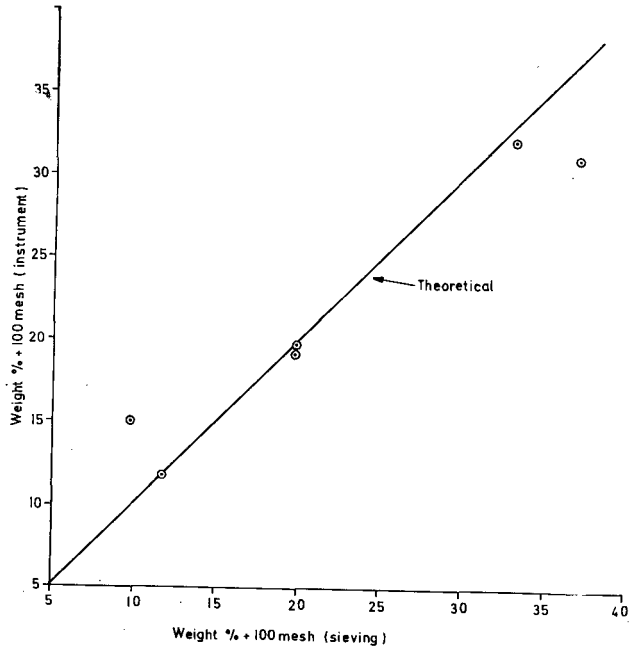

Fig. 2—Results of optical scanning with a laser beam

Results of preliminary laboratory tests are shown in Fig. 2. Although these results look promising, the prototype instrument was unable to yield accurate results when subjected to in-plant tests[8]. The presence of minus 44-μm material was found to be responsible for irreproducible results and output bore a direct relationship to the concentration of solids in the sample. Some improvement in results was obtained by removing all of the minus 44-μm material and maintaining the solids concentration to between 0,5 per cent and 1 per cent solids by weight. In spite of such elaborate precautions an accuracy of $\pm 8{,}8$ per cent $+100$ mesh was obtained.

OPTICAL GRATING METHOD

This method[1] has many of the characteristics of the elutriation and scanning techniques, and consequently suffers from similar deficiencies. However, lessons learnt from development of the method at the Chamber of Mines Research Laboratories are worthy of discussion.

In this method, which was based on the relationship between particle size and settling velocities, particles travel downwards in a stream of water flowing through a transparent flow cell at a velocity V_o (2 cm. sec^{-1}). The particles pass through an area illuminated by a collimated beam of light and the shadows produced by the particles pass over an optical grating composed of alternate horizontal opaque and transparent strips (each of width d/2) and are projected onto a silicon photocell. Each particle passing through the beam of light will produce an alternating response on the photocell of amplitude proportional to the projected surface area and frequency given by $(V_o + V_t)/\mathrm{d}$ where V_t is the terminal velocity of the particle in water. With N randomly distributed particles of a given size range in the light

beam at any time the amplitude of the signal at the photocell is proportional to $N^{\frac{1}{2}}$. In the prototype instrument (composed of four frequency channels) signals appropriate to a given frequency range are amplified and then processed in electronic squaring and integrating circuits. The output from the analyser therefore consists of time-integrated readings from four channels, each of which is a measure of the number of particles within a given size range.

Fig. 3—Results of optical grating method

The results of in-plant tests with the instrument are shown in Fig. 3. This graph shows that results were poor and that the instrument, if used for control of mill circuits, would have contributed significantly to over-grinding rather than preventing it. Poor results could be attributed partly to the deficiencies outlined previously for the elutriation and scanning methods. Agglomeration of fine material was particularly pronounced. Experiments in which identical size distributions were used of particles slurried in either water or alcohol yielded large differences in the number of fine particles recorded by the analyser, more particles being counted when alcohol was used as the dispersing agent. Perhaps the greatest problem was due to the vast number of fine particles. The electronic equipment was incapable of handling signals from the fine particles, even at moderate levels of dilution. This was alleviated by diluting the slurry to the extent that less than 100 milligrams of solids were analysed per minute. Scatter of results at this high level of dilution could be attributed to statistical fluctuations due to sample size being too small. Signals from air bubbles in the flow cell also contributed to the problems when low concentrations were used. A further deficiency of the method was that the "observed" size distribution departed from its true form because the residence time distribution of the particles in the flow cell was size-dependent. This led to a considerable reduction in the sensitivity to large particles of the instrument.

Although modifications to overcome some of the problems outlined above could be envisaged, development of the method was abandoned on the grounds that it showed little promise of success.

SIZE MEASUREMENT BY UTILISING DIFFRACTION OF LIGHT

The recent advent of commercially available gas lasers has created new possibilities in the use of diffraction techniques for real-time size analysis. In this method the size distribution is calculated from the intensity distribution of the diffraction pattern at infinity of a coherent light beam passed through a dilute suspension of the slurry.

Research on development of the method has been reported by Cornillault[9]. His particle size analyser is capable of handling about one gram of solids in less than ten minutes and can determine distribution curves for particle sizes from 2 μm to 500 μm. An experimental instrument is shown schematically in Fig. 4. A mechanical stirrer and ultrasonic generator are used to produce a general homogenisation and to disperse fine particles prior to their passage through the flow cell. The light source is a helium-neon laser with beam expanding telescope and spatial filter. For reliable results the equipment must have good mechanical stability. The diffraction pattern is focussed onto a photo-electric receiver at the focal plane of a lens well corrected for Seidel aberrations. A rotating screen is placed in front of the detector with transparent windows located at different radial distances. By moving the detector and rotating the screen it is possible to determine the intensity of the diffraction pattern and consequently derive the size distribution of the diffracting particles. The method is attractive in that it is fundamental and that calibration is necessary only to account for laser power and the transmissivity of optics. Reproducibility of results is reported to be within 2 per cent and to show good agreement with other sizing methods. Comparison between sieving and diffraction results is shown in Fig. 5. The correlation is remarkably good and it would seem that preliminary results are very encouraging. It must be pointed out that experiments have been conducted only under idealised laboratory conditions and consequently the method has still to be investigated thoroughly before a fair appraisal of its potential for industrial use can be made.

SIEVING TECHNIQUES

Sieving has received little attention as a rapid method of size assessment for mineral slurries. It has been dismissed for real-time analysis on the grounds that it is a very slow and tedious process. Much time is spent in drying samples prior to sieving and weighing. Although sieving is a highly empirical process, reproducible results can be achieved if the sieving process is carefully standardised. As a consequence of this good reproducibility sieving is the method of size analysis most commonly practised by the industry and any successful real-time size analyser should in principle be capable of yielding results which correlate well with sieving analyses.

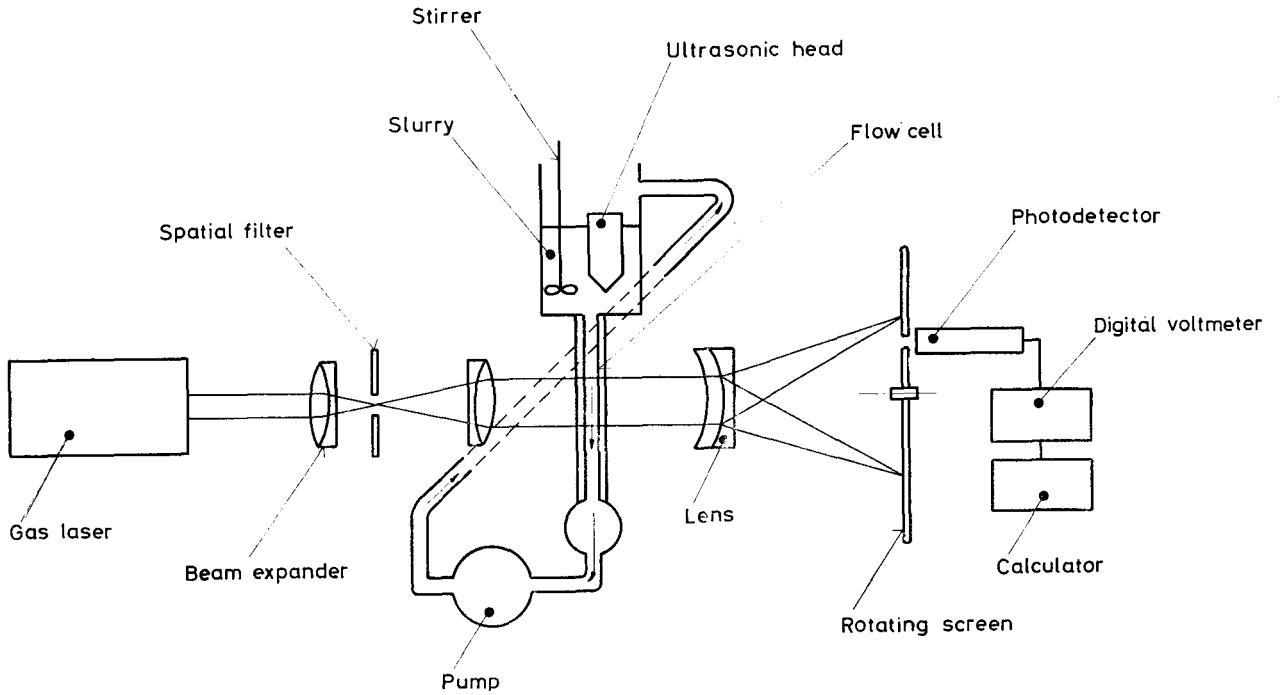

Fig. 4—Size analysis by diffraction of light

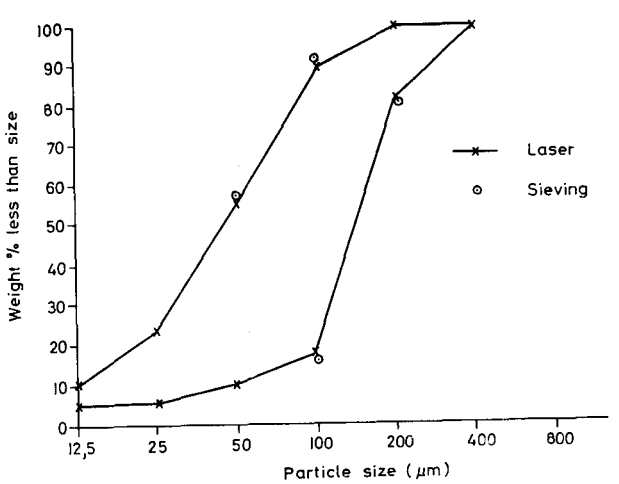

Fig. 5—Results of diffraction method

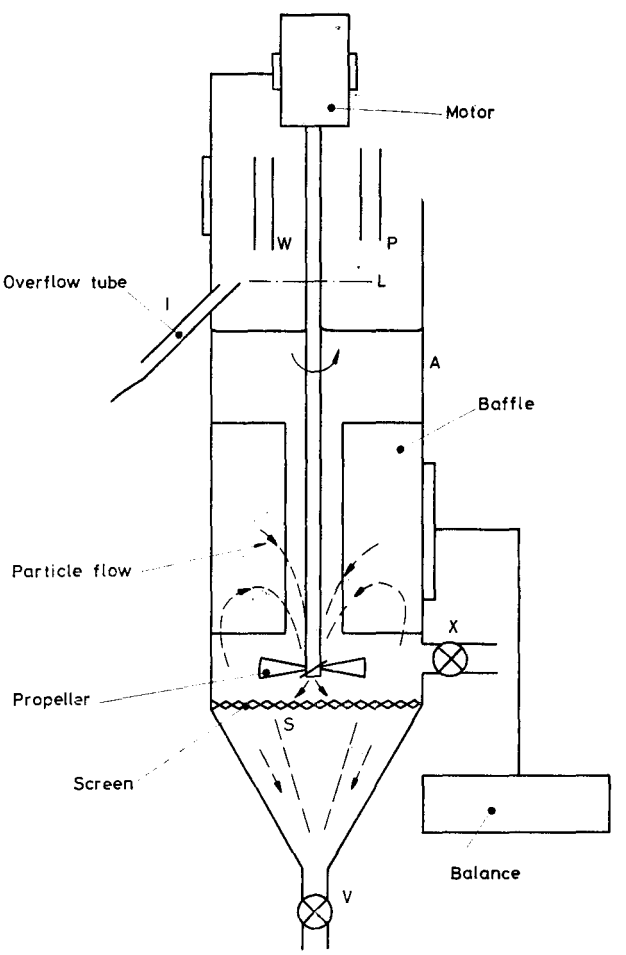

Fig. 6—A wet sieving device

It will now be demonstrated that sieving need not be so time consuming as it is commonly thought to be. Screen analyses can be accomplished in a few minutes without any need to dry samples either before or after sieving[10]. The method to be described has as its basis the assessment of the weight of the material on the screen by Archimedes' principle. The method may be demonstrated with reference to Fig. 6. Vessel A is filled with water via pipe W to a known level L determined by the overflow tube I, the valves V and X being shut. The vessel is then weighed (let this weight be W_w). The level of water is then lowered to the vicinity of the screen S containing apertures of known size, by opening V and/or X. The valves are then closed and the slurry to be sized is admitted via pipe P to the level L. The vessel is again weighed (let this weight be W_B). The valve V is then opened and water is admitted via pipe W to wash all particles finer than the screen size through the screen. A propeller driven by a small D.C. motor facilitates a rapid sieving action without excessive blinding and pegging. In the absence of mechanical agitation the screen blinds severely and sieving cannot be effected by supplying water alone. The use of ultrasonics for keeping the screen clear of pegged material could also be used to reduce the time taken for screening. Once all particles which can do so have passed the screen, as shown by the emergence of clear water through the valve V, the valve V is closed and water is added via pipe W up to the level L. The vessel is weighed a third time (let this weight be W_A). Then, by conventional physical principles, the weight of solids added initially to the vessel is $(W_B - W_w)/(1 - \rho_w/\rho_s)$ where ρ_w and ρ_s are the specific gravities of water and solids to be sized, respectively. Similarly the weight of solids remaining after the fine material has been washed out is given by $(W_A - W_w)/(1 - \rho_w/\rho_s)$. Thus the fraction by weight of solids coarser than the screen is given by $(W_A - W_w)/(W_B - W_w)$. On completion of the sieving and weighing operation the solids coarser than the screen may be flushed out of the vessel A through the valve X.

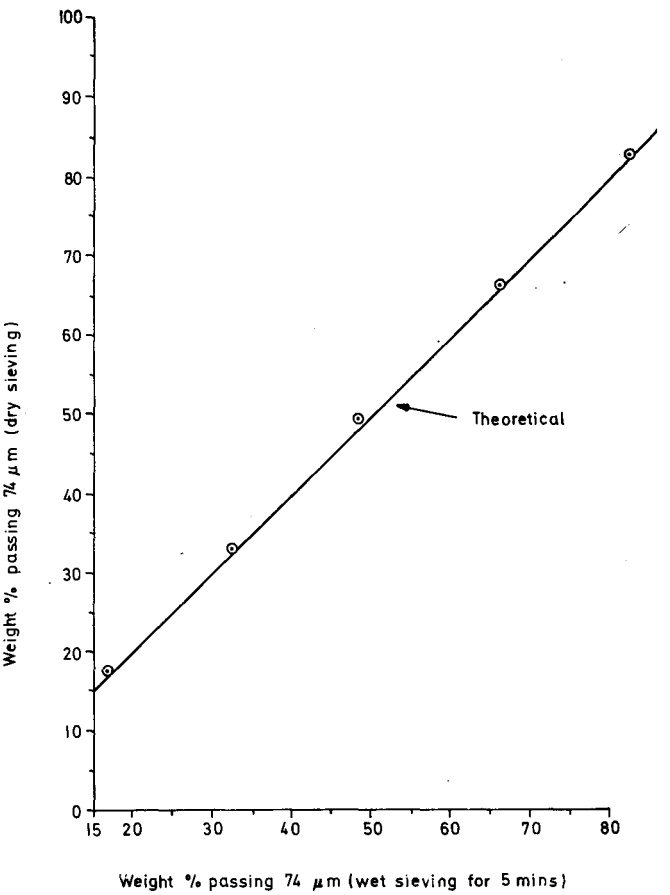

Fig. 7—Results of dry and wet sieving

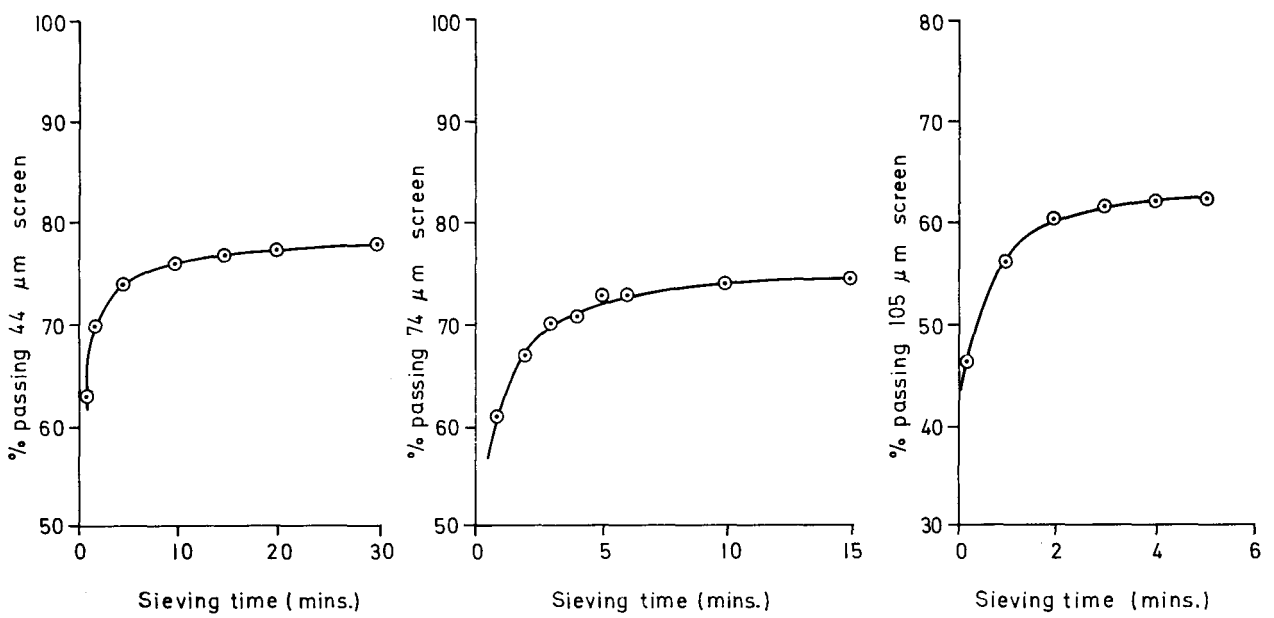

Fig. 8—Kinetics of wet sieving

The method was tested under laboratory conditions using 44-μm, 74-μm and 105-μm screens. Samples of between 20 and 25 grams of milled Witwatersrand gold ore were sieved dry by machine until the sieving rate of solids through the screen reached 0,1 per cent of the total sample weight per minute. This was taken to be the end-point for sieving. The samples were then made into slurries containing about 15 per cent solids by weight and sieved for fixed times in the wet sieving device. Results of dry and wet sieving on 74-μm screens are shown in Fig. 7. The kinetics of the sieving action in the wet sieving device are described in Fig. 8 which shows the percentage of material passing the screen as a function of time. Reproducibility of results was acceptable and errors amounted to less than 1 per cent passing given mesh size.

It has been pointed out that ore bodies can be composed of a mixture of minerals of different densities. If the average density of particles corresponding to a discrete size fraction is a function of particle size in a given sample, one would expect a method of size analysis based on wet sieving and Archimedes' principle to yield different results from the standard method of dry sieving and weighing. Fortunately this variation in average density with size for finely milled gold-bearing rock is generally small and rarely exceeds two or three per cent for particle sizes from a few tens of microns to a few hundred microns. It is instructive to give some indication of the sensitivity of the difference in results between dry sieving and the method of sieving described above to variations of average density with particle size.

Consider a sample which can be represented by the cumulative volume-size distribution $V(x)=f(x)$ and let the average specific gravity of the particles be a function $\rho_s(x)$ of particle size x. For dry sieving the cumulative weight fraction of particles less than size x is:

$$W_D(x)=\left[\int_o^x \rho_s(x) f'(x)dx\right]/\left[\int_o^\infty \rho_s(x) f'(x)dx\right]$$

where $f'(x)=\frac{d}{dx}\left[f(x)\right]$

Similarly for the wet-sieving method the cumulative weight fraction is

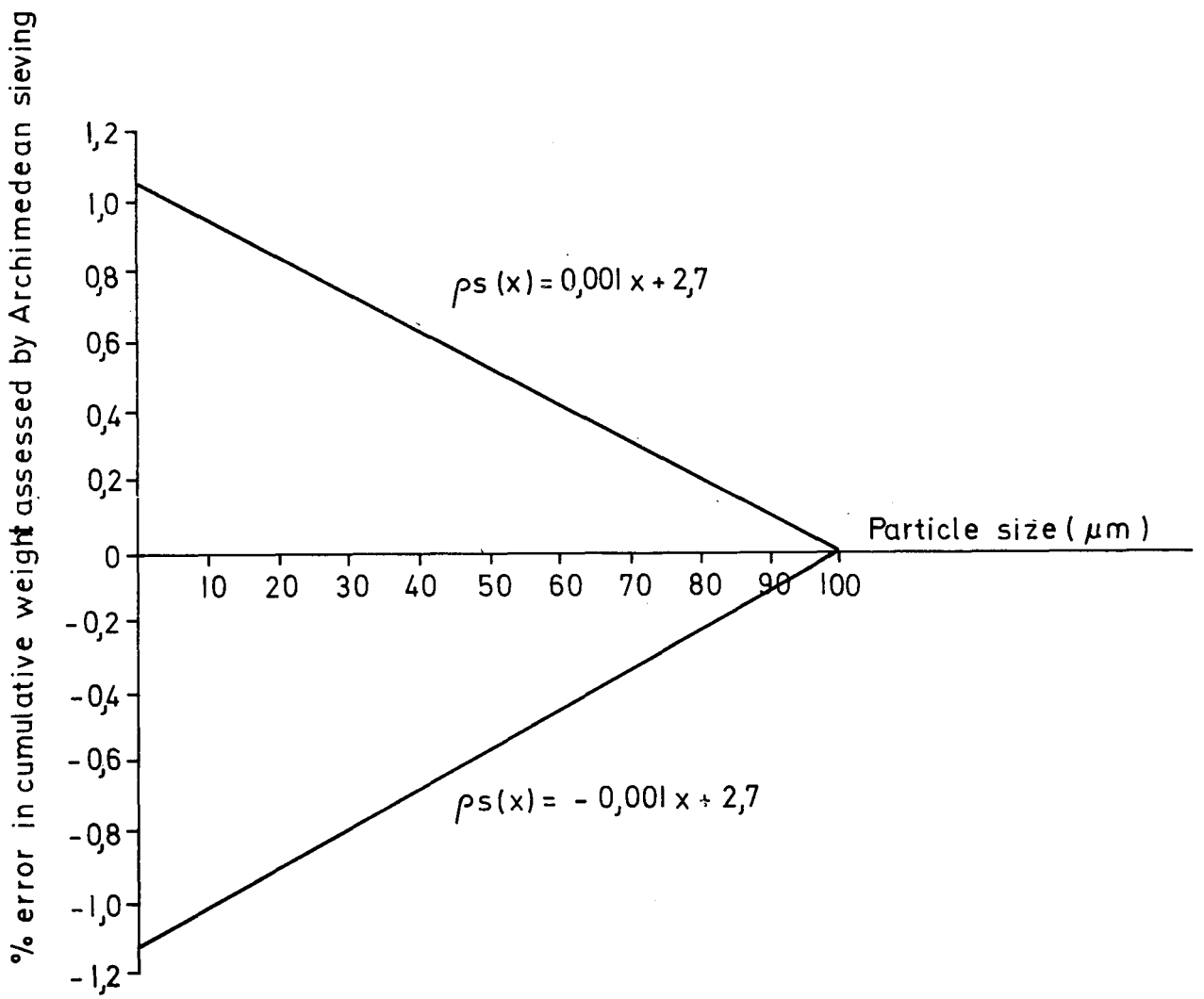

Fig. 9—Errors in weighing solids by Archimedes' principle

$$W_w(x)=\left\{\int_0^x\left[\rho_s(x)-\rho_w\right]f'(x)dx\right\}/$$

$$\left\{\int_0^\infty\left[\rho_s(x)-\rho_w\right]f'(x)dx\right\}$$

where ρ_w is the specific gravity of water.

In the limiting case where $\rho_s(x)$ is a constant independent of size $V(x)=W_D(x)=W_w(x)$, Fig. 9 shows the difference between the cumulative weight fraction $W_w(x)$ and $W_D(x)$ expressed as a percentage of $W_D(x)$ for the hypothetical case where

$$V(x)=\frac{x}{100}\ (\mu\text{m}) \quad \text{and}$$

$$\rho_s(x)=\pm 0{,}001x+2{,}7$$

This last equation represents approximately a 4 per cent variation in density from $x=0$ to $x=100$ μm. Even for such a wide density variation the value of $[W_D(x)-W_w(x)]/[W_D(x)]$ is only about 0,6 per cent at 44 μm and is zero at 100 μm. It follows that the wet-sieving method is relatively insensitive to the effects of variations of average density with particle size.

It is conceivable that a device based on this sieving method which incorporates appropriate limit alarms could be made automatic and be of considerable benefit to the industry. Development of such a device has recently been initiated in South Africa by Gunson Sortex Ltd.

METHOD INVOLVING SIZE SEGREGATION IN A HELICAL TUBE

In this method[11] a slurry containing between 10 and 30 per cent solids by weight is caused to flow under constant head conditions through a tube of rectangular cross-section. The tube is bent through one turn of a helix. In passing around the helix the particles are acted upon by centrifugal forces, drag forces, and other secondary effects causing the solids to move towards the outer wall of the flow tube. The magnitude of the displacement can be shown to be a function of particle size distribution.

In the "Mintek/RSM Size Analyser" (manufactured by the Cartner Group Ltd.) the density of the slurry is evaluated at different locations in the flow tube using β-ray transmission measurements. The instrument is calibrated by sieving, and it is then possible to translate these slurry density measurements into the cumulative weight fraction greater than some chosen mesh size. The instrument is relatively insensitive to variations in the specific gravity of the solid phase and can normally deal with material containing 5-90 per cent coarser than the calibration size. The accuracy of the instrument relative to sieving is reported to be:

$\pm$2,4 per cent+200 mesh
$\pm$2,4 per cent+170 mesh
$\pm$2,4 per cent+150 mesh

The figures quoted above correspond to a simplified calibration procedure requiring only one β-ray transmission measurement of the size-segregated slurry. A more refined calibration method involving two transmission measurements produces greater accuracy at the expense of complicating the data processing. By adopting the latter form of measurement an accuracy of $\pm$0,7 per cent+150 mesh is possible. It should be pointed out that many of the tests were conducted on material whose cumulative size distributions were of Schumann form with constant slope (constant distribution modulus). It is known that gross changes in ore grindability can, in some circumstances, produce distributions having various slopes. Tests were conducted on iron ore samples having such anomalous size distributions. The results of these tests are shown in Fig. 10 where an accuracy of $\pm$2,5 per cent+150 mesh was obtained using the more refined measurement procedure.

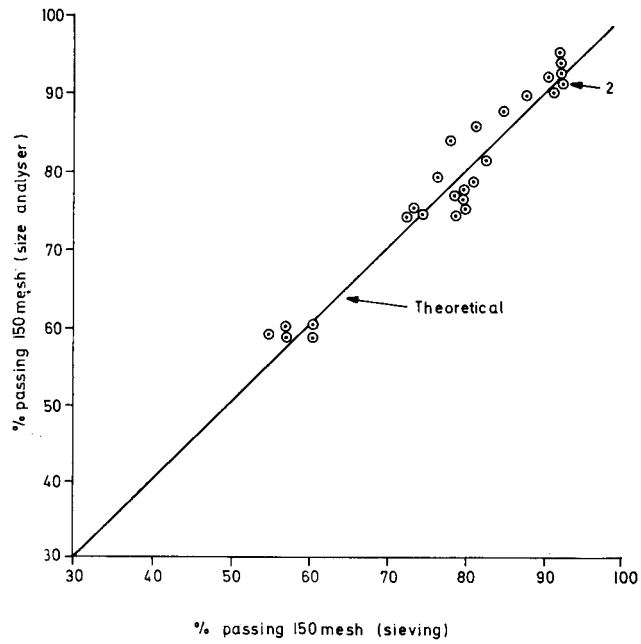

Fig. 10—Results obtained from the Mintek-RSM size analyser

METHOD BASED ON ULTRASONIC ATTENUATION

When ultrasonic energy in the frequency range 0,1 to 10 MHz is transmitted through a mineral ore slurry, losses occur due to viscous, scattering and diffraction effects. The frictional viscous loss is a result of the fact that particles in a sound field partake of the motion of the fluid to an extent determined by their mass, frequency of the ultrasonics, and the viscosity of the fluid. The scattering and diffraction losses represent a redistribution of energy rather than a dissipation of the energy of the primary beam. Theory and experiment show that the absorption coefficient is a function of frequency, particle size distribution and volume concentration. Thus by careful choice of operating frequencies it is possible to evaluate both solids concentration and particle size.

The method has been developed successfully by Autometrics Co. who now manufacture an on-line particle size analyser ("PSM System-100"). The analyser required over four years of intensive in-plant testing

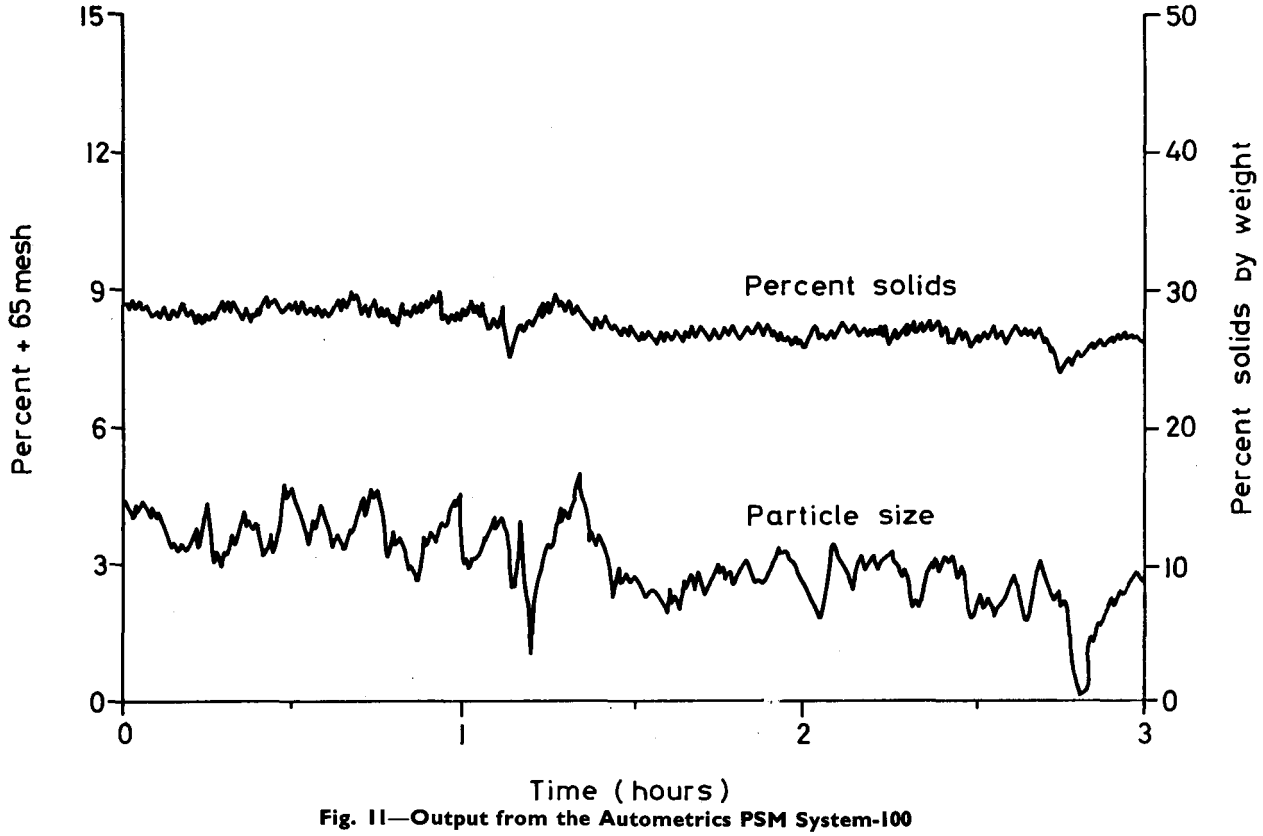

Fig. 11—Output from the Autometrics PSM System-100

before success was achieved. Hathaway[12] has described the problems which arose in the development of the method, some of which are outlined below.

1. Entrained air occurs in varying amounts; it must be stabilised or removed to allow accurate measurement of particle size.
2. Variation in temperature of the sample can cause errors in measurement by affecting fluid viscosity and sensor characteristics.
3. Wood chips and other contaminants can rapidly clog flow channels and cause misleading size readings.
4. Unexpected losses in sample flow occur under a variety of conditions, such as sanding of lines, and the system must be self-protecting against consequences of such an event.
5. Corrosion and scaling can occur rapidly and affect the measurement in a variety of ways.
6. Abrasive wear of parts exposed to the slurry can affect measurements.
7. The constant vibration of the mill floor can cause failures of both mechanical and electrical components.
8. The system must withstand contaminants such as dust, slurry reagents, and water from clean-up by hose-down.

Perhaps the greatest problem which had to be solved was that arising from entrained air which can affect results seriously because of resonant scattering of the ultrasonic energy by air bubbles. The problem was solved by removing the air with a novel device which utilises a combination of centrifugal force and reduced pressure.

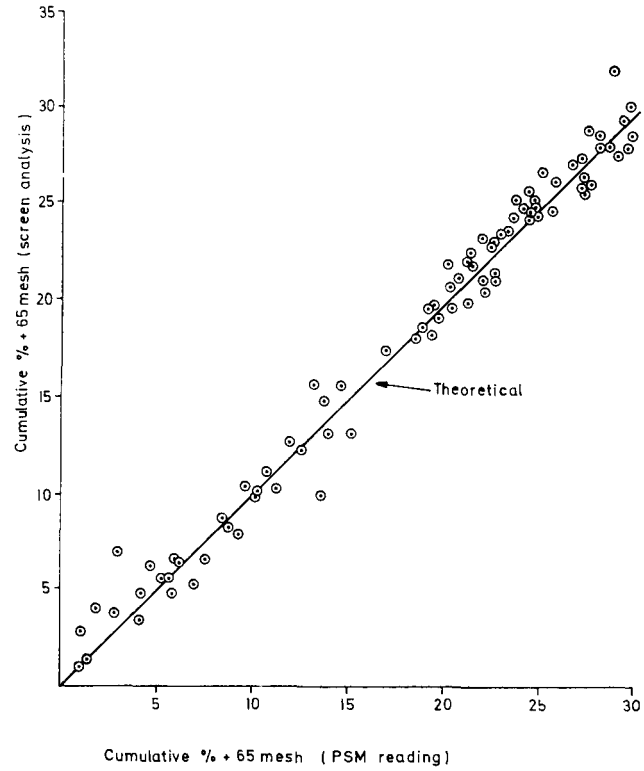

Fig. 12—Results obtained with the Autometrics PSM System-100

The sensitivity of the instrument to variations in particle size looks remarkably good, as shown in Fig. 11 which represents the output from the system. Accuracy of results compared with sieve analyses is also very good, as Fig. 12 indicates. At Magma Copper Mine Co. in Arizona, U.S.A., 286 samples were analysed over a three-month period and results yielded a mean square error of ±0,64 per cent+65 mesh.

The use of the analyser for control of milling circuits has resulted in a uniform grind (±0,5 per cent on the control screen fraction) and improved throughputs of between 4 and 12 per cent greater than similar circuits operating without the use of an on-line sizer. It has been calculated[13] approximately that with a 5 per cent increase in throughput and a uniform grind (obtained by size control) the Inspiration Consolidated Copper Co., U.S.A. could pay for a control system in less than a year (cost of "PSM System-100" about 30 000 U.S. dollars).

CONCLUSIONS

This review has endeavoured to show that the quest for a successful real-time size analyser has been fraught with difficulties. The ideal instrument which can determine the complete size distribution of particulate matter in process streams has yet to be developed. However, a thorough paper study of the physical principles involved in the design of a real-time analyser will often indicate whether the principles selected are likely to lead to a potentially useful design. Neglect of this step has in the past led to some abortive attempts to develop analysers.

The best instruments available currently are capable of determining accurately only one point on the cumulative size distribution curve. Although knowledge of a single point may be sufficient for significant improvements in the control of grinding circuits, it may not be adequate for a full understanding of the complex nature of large-scale extraction processes and the behaviour of processing equipment handling large tonnages.

Unfortunately the industry is now faced with the dilemma that although on-line size analysers are available, the benefits (other than benefits from control of milling circuits) which can be derived from their use have still to be determined fully. Since commercial on-line sizers involve considerable capital outlay there has been some reluctance by the industry to purchase these instruments until their usefulness can be evaluated. Since their usefulness can only be proved from intensive in-plant tests a stalemate has developed. It is hoped that the dilemma will be resolved in the near future and that the potential of real-time size analysers in the mining and metallurgical industry will begin to be realised.

ACKNOWLEDGEMENTS

The author would like to express his thanks to Dr P. J. Lloyd and Dr D. A. White for friendly and stimulating discussions and to the Chamber of Mines of South Africa for permission to publish this paper.

APPENDIX

Some definitions of terminology

Real-time size analyser: size analyser characterised by a process time for yielding size distributions which is sufficiently rapid to allow control of process streams.

On-line size analyser: a real-time size analyser in which the size sensor is located in the process stream or in a parallel sampling stream and by means of which continuous measurements are made of the size distribution.

Off-line size analyser: a real-time size analyser in which size assessment is done in a batchwise manner by extracting representative samples intermittently.

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DISCUSSION

J. H. TALBOT

The diffraction technique of particle size analysis had its origin in South Africa, and it is here that it has been most actively developed and has reached its highest standard of perfection. The first instrument to be available commercially was the Talbot Disa (acronym for diffraction size analyzer) manufactured by the Corner House Laboratories under an agreement with the Chamber of Mines of South Africa.

In the diffraction size analyzer the size distribution is obtained by Fourier inversion and differentiation of the power spectrum of the object. The operations are all done optically and the size distribution is obtained directly.

About two and a half years ago, the development of the diffraction method of size analysis took a new direction in South Africa with the invention of the spatial period spectrometer[1]. To understand this new development, it must be appreciated that the conventional diffractometer yields a Fourier analysis of

the object in the form of a spatial frequency spectrum. In the spatial period spectrometer, Fourier analysis is done in such a way as to yield a spatial period spectrum. The advantage is that spatial period has the dimensions of length and the spatial period spectrum is, therefore, a true size spectrum. It avoids the problem of defining a unit entity.

Spatial period is a statistical parameter and therefore the spatial period spectrum may be used, like the Maxwell-Boltzmann distribution of statistical mechanics, to relate the macroscopic properties of a system to its microscopic structure[2].

Two models of the spatial period spectrometer are already available. These are the PM3 and PM31, manufactured in South Africa by Talbot Research. The PM31 is an attachment for use with a PM1 series Image Analyzer.

A real-time, on-line, size spectrometer, designated Model PM303, has been under development for more than two years and is expected to be available soon. The basic instrument consists of a sensing unit and a display unit. The sensing unit contains a diffractometer of the spatial period type with a flow cell of rectangular cross-section 400 mm × 5 mm. This flow cell allows 5 litres of suspension to be processed in one second. A typical mill pulp sample containing 100 g of solids can be processed in 30 seconds. To achieve more rapid processing, numbers of sensing units may be fastened together and their outputs connected in parallel to a single display unit. The sensing unit is 1 m long, 420 mm wide and 100 mm high.

Instruments can be provided for monitoring any of a number of normalised moments such as specific surface, mean linear dimension, mean volume etc. or for recording the spatial period spectrum in any number of size intervals.

Owing to the translational invariance of the spatial period spectrum, aggregation is not as serious a problem as with most other methods.

A novel feature of the PM303 is the use of variance detection, our proprietary system of signal-to-noise ratio improvement. With this system the variance of the parameter is measured as an estimate of the parameter itself. This method eliminates low-frequency noise such as ambient diffracted light due to imperfect optical components, the Schlieren effect and particles depositing on lenses and cell windows, which would otherwise require frequent re-setting of the zero.

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ORANGE FREE STATE BRANCH

MINUTES OF THE COMMITTEE MEETING HELD IN THE WELKOM CLUB ON WEDNESDAY, 8th NOVEMBER, 1972

Present:

C. J. Isaac (in the Chair), E. T. Wilson, J. M. Meyer, C. Mostert, P. L. Nathan, D. A. Smith, R. Sutherland.

Apologies:

G. Young.

MINUTES OF THE PREVIOUS COMMITTEE MEETING

The minutes of the Committee Meeting held on the 19th January, 1972 were taken as read and their adoption was proposed by Mr J. M. Meyer and seconded by Mr E. T. Wilson.

There were no matters arising from these minutes.

GENERAL MEETINGS FOR THE ENSUING YEAR

It was agreed that the format of meetings used for the past year be continued for this year.

The following meetings were decided on:

Tuesday 30th January, 1973 — A film show "Nickel Mining in Canada" and "North Slope Alaska".

Tuesday 6th March, 1973 — An address by Anglo American Research Metallurgists on latest Gold Extraction methods.

End August, 1973 — Annual General Meeting to be addressed by the President of the Institute.

PROPOSED VISITS FOR THE ENSUING YEAR

It was decided that a visit be made to Vierfontein Colliery and Power Station on or about the 11th May, 1973.

It was further decided that a local visit be held in early August, 1973 to the following:

President Steyn — 4 Shaft — Surface, Shaft and Underground Station layouts.

Virginia — Task force training and Methane Fired Boilers.

NEXT COMMITTEE MEETING

It was decided that the next Committee Meeting should be held when Committee Members felt it necessary.

GENERAL

1. The Chairman read a letter from Professor Howat in which he thanked the O.F.S. Branch for his pleasant visit to Welkom.
2. It was suggested that the G.M.E. be approached to address a meeting of the O.F.S. Branch — Mr D. A. Smith to investigate.
3. It was suggested that the O.F.S. Branch hold itself responsible for the submission of at least 2 mining papers during the year.

The Chairman declared the meeting closed at 5.45 p.m.