SIMULATION OF A PROPOSED GRINDING CIRCUIT CHANGE TO REDUCE Pb SLIMING

by

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To my parents.

To my brothers for their encouragement.

To my wife Angeles for her patience.

To my son Raulito who has all to come.

ABSTRACT

A simulator has been constructed to investigate the decrease in Pb sliming achieved by incorporating a Pb flotation stage in a closed grinding circuit. The example is the Pine Point Mines Concentrator.

Models of ball mill, cyclone and flotation were developed permitting individual mineral-size behaviour to be followed. The mill model, in particular is discussed. A plug flow p-order kinetic model was used with laboratory derived parameters and a scale factor fitted to plant data. Scaling proved to be minor, except for PbS.

The simulator was successfully tested against present circuit operation at two tonnages. This required development of a mass-balancing data adjustment scheme to provide self-consistent mineral-size assays.

The predicted performance of the proposed circuit indicated a considerable coarsening of PbS was possible. Also revealed was an added recovery effect due to cyclone action.

Résumé

Un simulateur a été construit pour étudier la diminution de slimage de Pb obtenu en incorporant un étage de flottation de Pb dans un circuit fermé de broyage. L'exemple est le concentrateur de Pine Point Mines Ltée.

Des modèles de broyeur à boulets, cyclone et de flottation on été développés pour permettre de suivre les comportements individuels de differentes tailles de minerai. En particulier le modèle du broyeur à boulets est discuté. Un modèle cinétique d'écoulement piston à l'ordre p a été utilisé avec des paramètres trouvés au laboratoire, et un facteur d'échelle ajusté à des données industrielles. On a montré que le facteur d'échelle était petit, sauf pour le PbS.

Le simulateur a été testé avec succès sur le présent circuit à deux tonnages. Ceci a nécessité le développement d'un scheme d'ajustement de données d'équilibrage de masse pour fournir des essais en accord avec la taille des minerais.

Le fonctionnement prévu du circuit proposé a indiqué qu'un grossissement considérable du PbS était possible. Un effet de récupération supplémentaire dû à l'action du cyclone a aussi été révélé.

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GLOSSARY

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Ball mill holdup, BMH - ball mill volume occupied by pulp, m^3.

Mean residence time, τ - time the pulp remains in mill given by BMH/pulp volumetric flow rate.

Homogeneous materials - materials with uniform properties (e.g. hardness and specific gravity), i.e. single mineral species.

Heterogeneous materials - materials having a distribution of properties, i.e. ores composed of more than one mineral species.

Primary breakage - a single event of breakage

Breakage function, $B(x,y)$ or B_{ij} - a probabilistic function which expresses in fractional form the weight finer than size x (or screen number i) after primary breakage of particles of size y (or screen number j).

Selection for breakage function, $S(x)$ or S_i - or specific rate-of-breakage, is a probabilistic function which expresses the mass-fraction of the charge of size x, or screen number i, broken in unit of time, min^{-1}.

Cumulative-basis specific rate-of-breakage, k_i - rate of disappearance by breakage of a mass fraction of particles coarser than a given screen i, min^{-1}.

SECTION II - CLASSIFICATION

Selectivity index, Y - the mass fraction of solids of a given particle size in the feed reporting to the cyclone underflow.

Cyclone performance curve or selectivity curve - a plot of Y against particle size.

Cut-size d_{50} - particle size for which Y = 0.5 and represents particles with equal (50 percent) probability of reporting to either the overflow or underflow.

Short-circuiting, a - the limiting cyclone performance. It is the intercept on the Y-axis at zero particle size. Also is thought to represent the mass fraction of particles entrained and following the water split.

Water split, R_f - the mass fraction of cyclone feed water reporting to the underflow. R_f is frequently equated to a.

Classification index, Y' - the selectivity index Y, corrected for short-circuiting. The correction is $Y' = (Y - a)/(1 - a)$.

Corrected performance curve or classification curve - a plot of Y' against particle size.

Corrected cut-size, $d_{50(c)}$ - the particle size at which Y' = 0.5.

Sharpness of classification, n - a fitted parameter to an assumed form of the classification curve, namely

$$Y' = 1 - \exp\{- 0.693\{d/d_{50(c)}\}^n\}$$

n represents the 'steepness' of the curve. d is particle size.

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CHAPTER I

INTRODUCTION

The objective of grinding in tumbling mills, as practiced in the mineral processing industry, is to physically liberate the valuable mineral species from the gangue. Following liberation and depending on the type of ore, one or various mineral separation processes can be used. The success of the separation largely depends on the effectiveness with which the valuable grains are liberated without producing excessive amounts of slimes. Slimes, in terms of flotation recovery, can be considered as particles less than about 5 micrometers.[1]

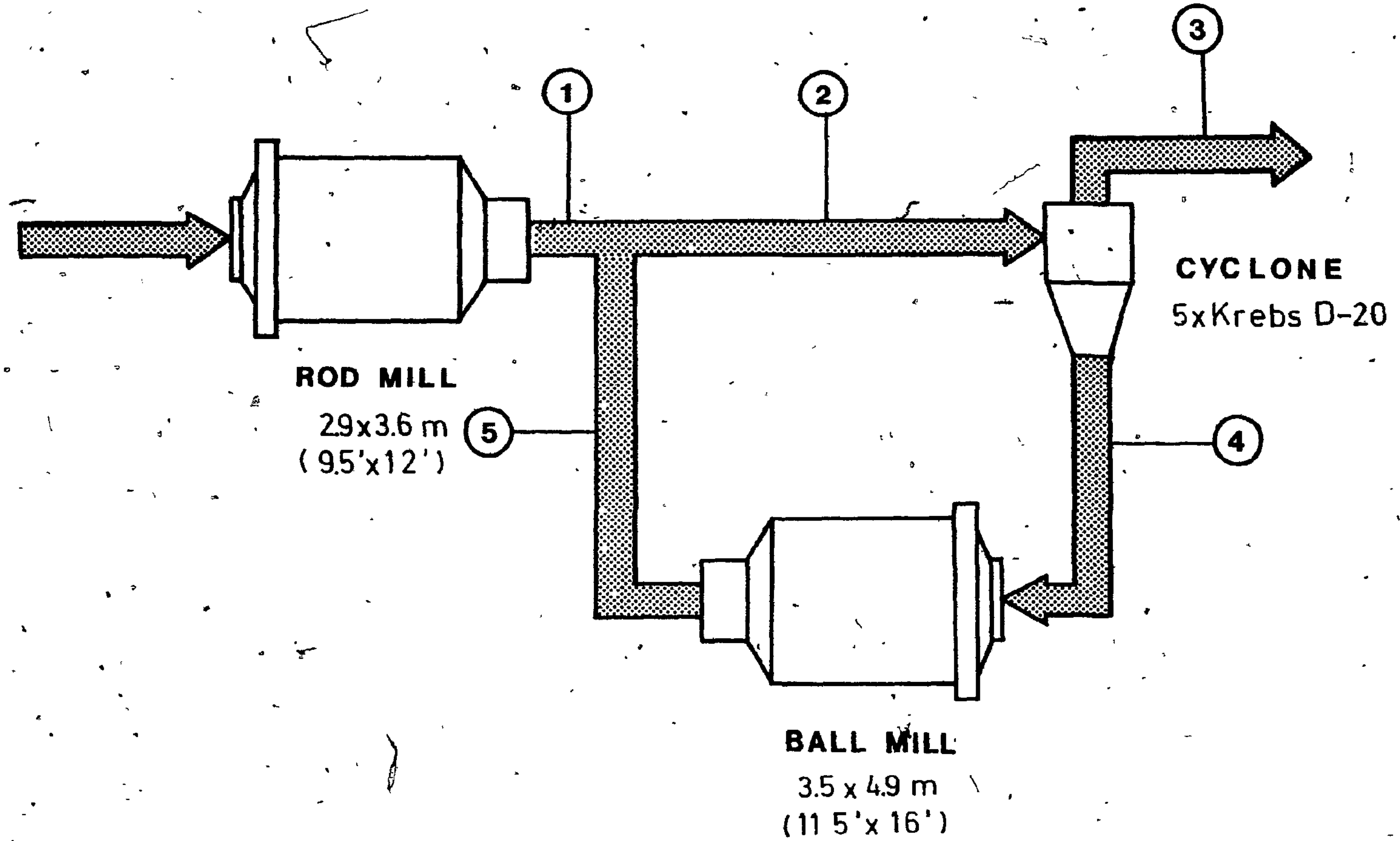
A typical closed wet grinding circuit is illustrated in Figure 1.1. This is the Pine Point Mines Concentrator No. 3 circuit which processes a lead (galena)-zinc (sphalerite) ore with pyrite and calcite/dolomite as the gangue components.

For the purpose of defining the objective of this study, it is instructive to examine the circuit performance with respect to the desired criterion of liberation with minimum fines, especially for galena.

First, consider the cyclone action. Separation is effected by a competition between a centrifugal force acting on the particle mass and a hydrodynamic drag acting on the particle surface. Particle mass is clearly dependent on size and specific gravity. A consequence is that for particles for which the hydrodynamic drag is equal, the ones with the higher specific gravity have a greater probability of reporting to the underflow. To a good approximation, in the circuit being

FIGURE 1.1

Actual closed grinding circuit No.3 at the Pine Point Mines Concentrator.



1
2
3
CYCLONE
5xKrebs D-20
ROD MILL
2.9x3.6 m
(9.5'x12')
5
4
BALL MILL
3.5 x 4.9 m
(11.5'x 16')

considered, equal hydrodynamic drag implies equal sized particles, as such highly shape dependent minerals, as mica, are absent. The corollary is that the higher density particles constitute the finer components of the cyclone overflow or flotation feed and liberated galena, being the highest density component, is concentrated in the closed circuit.

Secondly, the ball mill can be considered to act on each mineral component individually. Intuition, and some experience, suggests that the degree of grindability will increase from pyrite to galena (with sphalerite and calcite/dolomite in between), i.e. in order of mineral hardness. The recycled minerals will be individually size reduced depending on the grindability, and this will modify the mineral circulating load and cyclone overflow fineness.

Table 1.1 shows an example of this circuit performance on each mineral component. The circulating load is relative to the total (or overall) circulating load.

TABLE 1.1

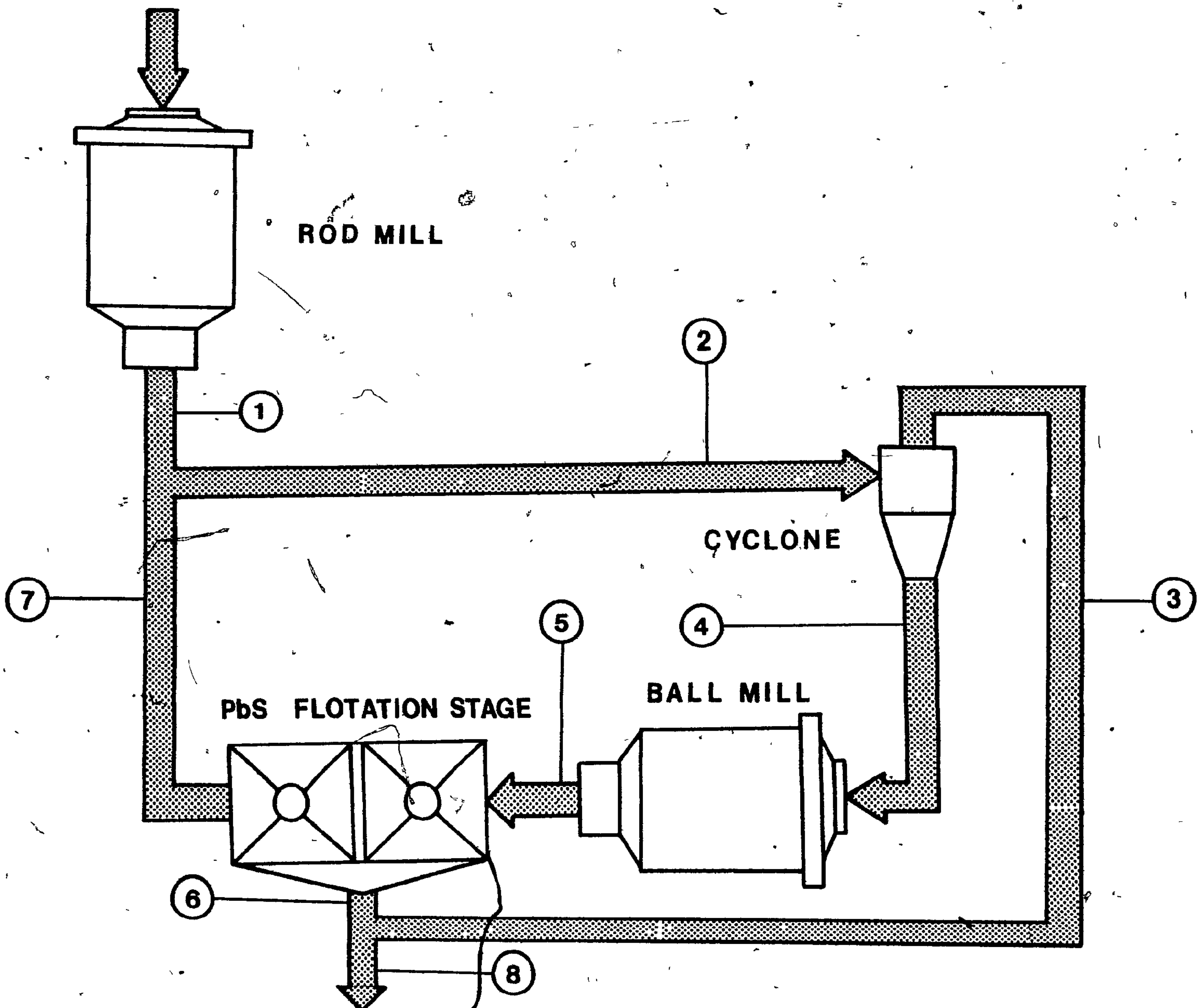
Performance of Pine Point Circuit (June 5, 1975) Ref. (2).

Mineral	% -200 Mesh in COF	Relative Circulating Load
galena	96.96	2.84
sphalerite	67.73	1.97
pyrite	73.36	1.65
CAL/DOL	47.33	0.74
overall	52.67	1.00

The recycling of liberated galena, coupled with the extreme fineness of the flotation feed appears to violate the criteria of liberation with minimum slimes. To emphasize, the slimes can cause flotation recovery and equally importantly, dewatering problems. A proposed solution is to remove ('bleed') the closed circuit of galena by imposing a PbS flotation step on the ball mill discharge. The modified circuit is shown in Fig. 1.2. This scheme has been successfully employed at other locations.[3,4] The objective of this thesis is to develop a model of the closed circuit grinding capable of yielding information on each mineral component individually. This model will be used to give a first estimate of the circuit changes to be expected from incorporating a ball mill discharge PbS flotation step.

FIGURE 1.2

Proposed closed grinding circuit. The circuit incorporates a PbS flotation stage after the ball mill.


ROD MILL
1
2
CYCLONE
3
4
5
7
BALL MILL
PbS FLOTATION STAGE
6
8

CHAPTER II

THEORY

2.1 Grinding

Grinding is a unit operation which has no sound underlying theory compared to other unit operations in chemical engineering as, for example, distillation or heat transfer. Such a situation is due to the fact that grinding is a very complex operation in which many variables interact at the same time. To mention only a few of them, the following are outstanding factors affecting the operation:

a) Ore type[5] (geological history, distribution of flaws, mineral composition, hardness).

b) Grinding mill type[6.a] (rod, ball or other) and overflow or grate type[6.b].

c) Wet or dry.[6.c,7.a]

d) Loading conditions[8,9] (grinding media and solids holdup).

e) Grinding circuit configuration.[10]

f) Operating variables[11] (flow rates, slurry consistency, particle size distributions).

Two basic mathematical approaches have been developed to describe the process of grinding. These are: energy-consumption based models and mass-size balance models. From the former only the Bond Model remains of practical usefulness. However, the Bond Model is not suited to simulation. For this purpose, the mass-size balance or population balance model has been developed and is now widely employed as an aid for assessing changes to actual flowsheets. The following sections review briefly the development of the main grinding theories and their contribution to the present state of knowledge.

2.1.1 Energy Consumption Models

Rittinger[12], in 1867 postulated that the energy required for size reduction of a solid is proportional to the new surface area created. In mathematical form:

$$E_R = K(\sigma_2 - \sigma_1) \qquad (2.1)$$

or,

$$E_R = K'(1/x_2 - 1/x_1) \qquad (2.1a)$$

where E_R = energy/unit volume

σ_2 = product surface area/unit volume

σ_1 = feed surface area/unit volume

x_2 = product size

x_1 = feed size

K and K' = constants

Kick[13], in 1885 proposed the theory that equivalent amounts of energy result in equivalent geometric changes in size. In mathematical form:

$$E_K = K'' \log \frac{F}{P}$$

where E_K = energy/unit volume
F = feed size
P = product size
K'' = constant

Bond[14], in 1952 proposed a model which is a compromise between the previous theories of comminution. This is the well-known Third Law of Comminution. The equation is as follows:

$$E_B = K'''\left(\frac{1}{\sqrt{P}} - \frac{1}{\sqrt{F}}\right)$$

where E_B = energy/unit volume
K''' = constant
P = the cumulative 80% by weight passing product size
F = the cumulative 80% by weight passing feed size

The model is based on the empirical experience that:

$$\text{time of grinding} \propto \left(\frac{1}{\sqrt{P}} - \frac{1}{\sqrt{F}}\right) \quad (2.4)$$

where P and F are as defined above.

Bond defines an additional concept: the work index W_i. It is defined as the energy/short ton required to reduce an infinite-sized particle to 80% passing 100 micrometres.

$$\text{Or,} \quad W_i = K'''\left(\frac{1}{\sqrt{100}} - \frac{1}{\sqrt{\infty}}\right) \quad (2.5)$$

$$\therefore \quad K''' = 10\,W_i$$

$$\text{Finally,} \quad W = 10\,W_i\left(\frac{1}{\sqrt{P}} - \frac{1}{\sqrt{F}}\right) \quad (2.6)$$

This is the familiar relationship widely used by engineers in sizing grinding mills.[15] The work index W_i is a measure of the grindability of an ore; the higher the value, the harder the ore and the more energy required for grinding.

Determination of W_i can be made by[16]:

a) Direct estimation (laboratory);

b) Comparison technique (laboratory);

c) From plant operation data.

The model has proven to be successful for mill sizing. Its empirical base means it should be applied with caution. Several correction factors are often incorporated.[15]

2.1.2 The Size-Mass Balance Model

The energy-consumption models, although useful for certain purposes, lack the ideal requirement of a mathematical model able to predict the size-mass product of an ore subjected to grinding. Due to that fundamental requirement, some pioneer theorists began to formulate a new theory of grinding.

The following is a brief review of the development of the theory.

Epstein[17] was the first to introduce the two basic comminution functions: the selection for breakage function S(x) which expresses the mass-fraction of size x selected for breakage; and the breakage function B(x,y), which gives the mass-fraction finer than size x after primary breakage of particles of size y.

Bass (as quoted by Harris[18]) was the first to introduce a fundamental mass balance for batch grinding as an integro-differential equation of the form:

$$\frac{\partial^2 F(x,t)}{\partial x \partial t} = \int_x^{x_m} \frac{\partial B(x,y)}{\partial x} S(y) \frac{\partial F(y,t)}{\partial y} dy - S(x) \frac{\partial F(x,t)}{\partial x} \quad \ldots\ldots(2.1.1)$$

where $F(x,t)$ = cumulative weight fraction finer than size x after grinding for time t a feed having a size distribution $F(x,0)$

x_m = maximum particle size

x = lower particle size

y = upper particle size

$B(x,y)$ = breakage function (non-cumulative)

$S(x)$ = selection function or specific rate of breakage

Fig. 2.1 shows in schematic form the meaning of the $B(x,y)$ and $S(x)$ concepts. The symbol G in the figure denotes the primary breakage event. The white areas shown represent the mass fractions selected for breakage (the selection function $S(x)$), while the frequency distributions at the right represent the breakage function $B(x,y)$.

Austin[19] formulated a general equation for batch grinding in cumulative form as follows:

$$dw_i(t)/dt = \sum_{\substack{j = i-1 \\ i > 1}}^{1} S_j(b_{i,j} - b_{i+1,j})w_j(t) - S_i w_i(t) \quad \text{.....(2.1.2)}$$

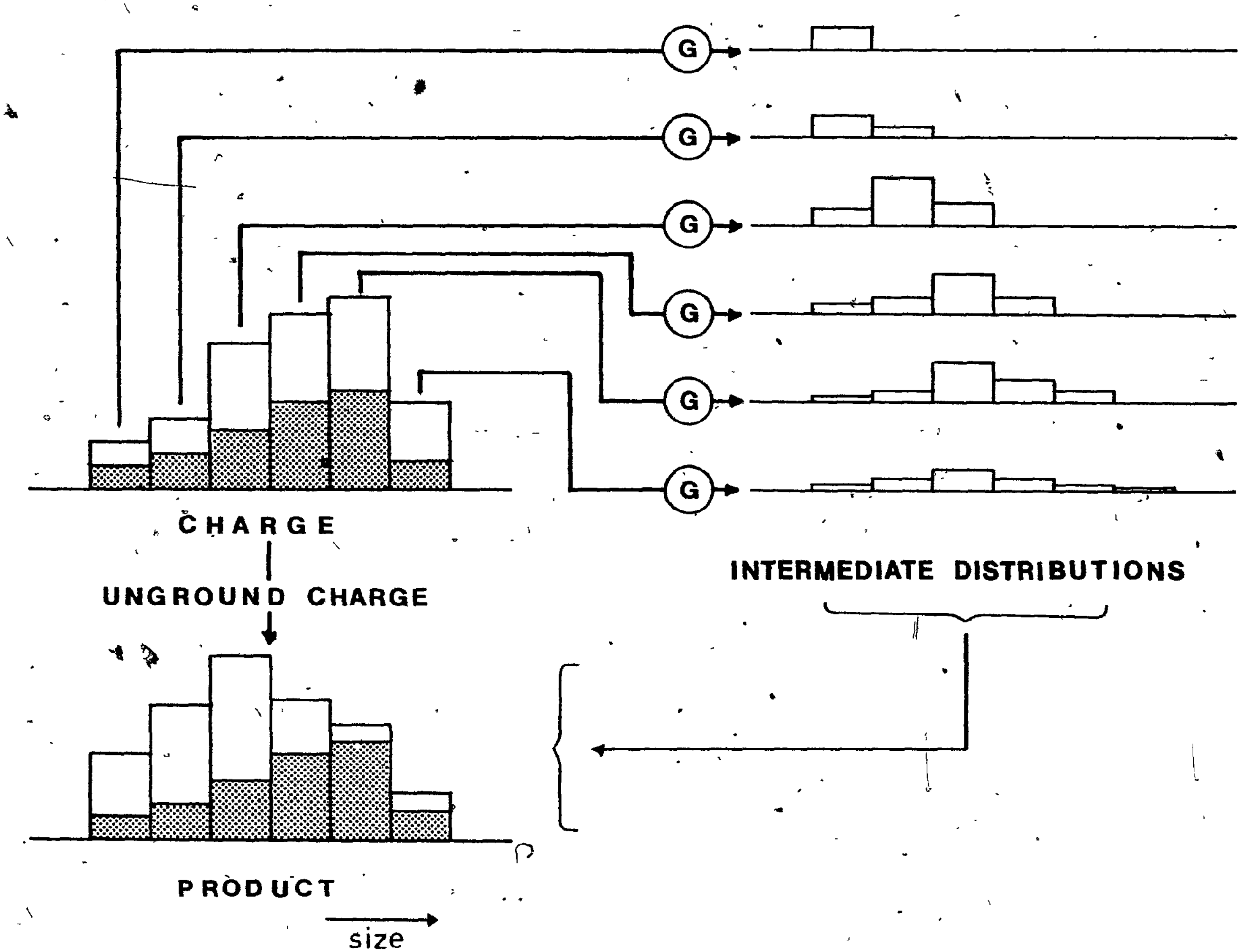
where i and j are screen numbers ($i = 1$ is the top screen and $j > 1$)

$w_i(t)$ and $w_j(t)$ are the mass-fractions retained on screens i and j, respectively

S_i and S_j are specific rates of breakage (or selection functions) of particle sizes i and j, respectively. Units: time^{-1}.

FIGURE 2.1

Conceptual scheme of a unit of grinding. The breakage function is defined by the ground particle size distributions (right). The selection function is given by the mass fraction selected for grinding. G is a primary breakage event.


G
CHARGE
UNGROUND CHARGE
PRODUCT
size
INTERMEDIATE DISTRIBUTIONS

$b_{i,j}$ is the cumulative breakage function. It gives the mass-fractional of material broken out of size interval j which falls below the upper size of size interval i.

In Appendix I, methods used to determine S(x) and b(x,y) (or $b_{i,j}$) are discussed. An equivalent equation to Eq.(2.1.2) is the following equation used by Luckie and Austin[20]:

$$dw_i(t)/dt = \sum_{\substack{j=1 \\ i>1}}^{i-1} S_j B_{i,j} w_j(t) - S_i w_i(t) \qquad (2.1.2a)$$

where $B_{i,j}$ is the breakage distribution of size j which is broken into size i

$$= b_{i,j} - b_{i+1,j}$$

If S does not vary with time, Reid[21] has shown that the solution to Eq.(2.1.2a) is as follows:

$$w_1(t) = w_1(0) \exp(-S_1 t)$$

$$w_2(t) = w_1(0) \frac{S_1 B_{2,1}}{S_2 - S_1} \exp(-S_1 t) + \{w_2(0) - \frac{S_1 B_{2,1}}{S_2 - S_1} w_1(0)\}$$

$$\exp(-S_2 t)$$

$$\vdots$$

$$w_i(t) = \sum_{j=1}^{i} a_{i,j} \exp(-S_j t) \qquad (2.1.3)$$

where

$$a_{i,j} = \begin{cases} 0 & , \ i < j \\ w_i(0) - \sum_{k=1}^{i-1} a_{i,k} & , \ i = j \\ \frac{1}{S_i - S_j} \sum_{k=j}^{i-1} S_k B_{i,k} a_{k,j} & , \ i > j \end{cases} \qquad (2.1.3a)$$

Equation (2.1.3) also can be expressed in a slightly different form:[20]

$$w_1(t) = \exp(-S_1 t) w_1(0)$$

$$w_2(t) = \frac{S_1 B_{2,1}}{S_2 - S_1} \{\exp(-S_1 t) - \exp(-S_2 t)\} w_1(0)$$

$$+ \exp(-S_1 t) w_2(0)$$

$$\vdots$$

$$w_i(t) = \sum_{j=1}^{i} d_{i,j} w_j(0) \qquad (2.1.4)$$

where

$$d_{i,j} = \begin{cases} 0 & , \ i < j \\ \exp(-S_1 t) & , \ i = j \\ \sum_{k=i}^{i-1} a_{i,k} a_{j,k} \\ \{\exp(-S_k t) - \exp(-S_i t)\} & , \ i > j \end{cases} \qquad (2.1.4a)$$

with

$$a_{i,j} = \begin{cases} -\sum_{k=j}^{j-1} a_{i,k} a_{j,k} & , \ i < j \\ 1 & , \ i = j \\ \frac{1}{S_i - S_j} \sum_{k=j}^{i-1} S_k B_{i,k} a_{k,j} & , \ i > j \end{cases}$$

Equations (2.1.3) and (2.1.4) are derived for batch grinding where S does not change with time. However, as stated by Luckie and Austin[20], the Reid solution becomes unstable for $S_i \rightarrow S_j$. To overcome the difficulty, they proposed the so-called finite difference solution given by

$$\{w_i(\Delta t) - w_i(0)\}/\Delta t = \sum_{\substack{j=1 \\ i>1}}^{i-1} S_j B_{i,j} \bar{w}_j - S_i \bar{w}_i$$

where Δt is chosen so that

$$\bar{w}_i = \{w_i(\Delta t) + w_i(0)\}/2.$$

Δt was suggested to be

$$\Delta t \leq 0.05/S_{max}$$

This solution to the batch grinding equation yields

$$w_1(\Delta t) = \frac{2 - S_1\Delta t}{2 + S_1\Delta t} w_1(0)$$

$$w_2(\Delta t) = \frac{2 - S_2\Delta t}{2 + S_2\Delta t} + \frac{S_1 \Delta t B_{21}}{2 + S_2 \Delta t} \cdot \frac{4}{2 + S_1\Delta t} \cdot w_1(0)$$

$$\vdots$$

$$w_i(\Delta t) = \sum_{j=1}^{i} d_{i,j}(\Delta t)\, w_j(0) \qquad (2.1.5)$$

where

$$d_{i,j} = \begin{cases} 0 & , \quad i < j \\ \dfrac{(2 - S_j\Delta t)}{(2 + S_i\Delta t)} & , \quad i = j \\ a_{i,j} & , \quad i > j \end{cases}$$

(2.1.5a)

and

$$d_{i,j} = \begin{cases} 0 & , \quad i < j \\ 4/(2 + S_i\Delta t) & , \quad i = j \\ \{1/(2 + S_i\Delta t)\} \cdot \displaystyle\sum_{k=j}^{i-1} S_k \,\Delta t \, B_{i,k}\, a_{k,j} & , \quad i > j \end{cases}$$

2.1.3 Cumulative-Basis Grinding Kinetics Model

The mass-size balance model described above has some important limitations when expanded to consider individual mineral grinding kinetics. For example, each mineral would require a determination of its own selection and breakage function which could be prohibitively cumbersome.[22,23] Further, the experimental determination of $S(x)$ requires closely sized fractions (see Appendix I). This is not realistic in that breakage occurs in an environment with a wide size range. There is evidence that coarse particles of one mineral 'protect' finer particles of a second mineral[24], a possibility which single size experiments on multimineral ores will miss.

The complexity implied by following each mineral individually suggested a simpler modelling procedure. The model investigated is based on that proposed by Harris[25-28] and Tanaka.[29]

2.1.3.1 First-Order Model

The first-order model is an extension of the Reid solution to the grinding equation (2.1.1) for the top size (i = 1) fraction.

Case 1 cumulative fraction coarser than Screen 1

$$C_1(t) = C_1(0)\exp(-k_1 t) \tag{2.1.6a}$$

Case 2 cumulative fraction coarser than Screen 2

$$C_2(t) = C_2(0)\exp(-k_2 t) \tag{2.1.6b}$$

.
.
.

Case i cumulative fraction coarser than Screen i

$$C_i(t) = C_i(0)\exp(-k_i t) \tag{2.1.6i}$$

.
.
.

Case n cumulative fraction coarser than Screen n

$$C_n(t) = C_n(0)\exp(-k_n t) \tag{2.1.6n}$$

where $C_1(t) = w_1(t)$

$$C_2(t) = w_1(t) + w_2(t)$$

$$\vdots$$

$$C_i(t) = w_1(t) + w_2(t) + \ldots + w_i(t)$$

$$\vdots$$

$$C_n(t) = w_1(t) + w_2(t) + \ldots + w_i(t) + \ldots + w_n(t)$$

Similarly,

$$C_1(0) = w_1(0), \text{ etc.}$$

$$k_1(t) = S_1(t)$$

$k_i(t)$ - cumulative-basis rate of breakage, $\min^{-1}$ of fraction coarser than Screen i.

n - is the finest screen.

An important aspect of Equations (2.1.6) is that they do not contain the breakage function B(x,y). Also the selection function S(x) has been avoided, and in its place a cumulative-basis selection function introduced.

This solution suffers by not being unique in the sense that k_i depends on the feed size distribution. However, if this does not change drastically, as is usually the case with an operating circuit, k_i will be constant. A practical difficulty is that first order may not be preserved over such large size intervals.[30] Nevertheless, examples where it is preserved are available.[31,32]

2.1.3.2 p-Order Model

The potential weakness of the first order equation (2.1.7) is that it does not fit all experimental results from batch grinding, particularly for the coarser fractions.[30,33] Such coarse fractions show a systematic deviation from first order kinetics known as 'abnormal breakage'.[9,34-36] The probable explanation for such 'abnormal breakage' is that the coarser fractions are always ground in a purely decaying manner without replenishment of the broken particles. In contrast, the intermediate and fine fractions are always broken under constant particulate population conditions. Consequently, the instantaneous or absolute rate of breakage of the coarse fractions is higher at the beginning and decreases with time, until eventual complete disappearance, in which case the instantaneous rate of breakage would be zero.

To account for such deviations, Harris[25-28] has proposed a non-first order fitting technique.

The equations suggested are the following:

Case I. Feed sizes do not contribute to the product.

$$C_i(t) = \exp(-b_i t^{p_i}) \qquad (2.1.7)$$

Note:

$C_i(0) = 1.0$

Case II. Feed sizes do contribute to the product.

$$C_i(t) = C_i(0)\ \exp(-\ b_i t^{p_i}) \qquad (2.1.8)$$

where:

$C_i(t)$ and $C_i(0)$ are as defined in the previous section;

b_i is the cumulative-basis specific rate of breakage of mass-fraction coarser than size i. Dimensions: time^{-p_i}.

p_i is the order of grinding kinetics of mass fraction coarser than size i. Dimensionless.

and

b_i and p_i can be determined by a least squares technique on batch grinding results.

The equations analysed are:

$$\ln\ \ln\ \{C_i(t)\} = -\ p_i \ln t + \ln b_i \qquad (2.1.7a)$$

and,

$$\ln\ \ln\ \{\frac{C_i(0)}{C_i(t)}\} = p_i \ln t + \ln b_i \qquad (2.1.8a)$$

For Cases I and II, respectively. Note, the p-order model reduces to the first-order model if p = 1. Also, an instantaneous rate of breakage can be defined as:

$$\bar{k}_i = b_i t^{p_i - 1} \qquad (2.1.9)$$

Tanaka and Selby[29] developed a model similar to that of Harris. In this, it is recognized that b_i is a function of particle size. Several possible forms of this function have been suggested[37];

the one assumed was:

$$b_i = Kx^{\alpha}$$

where K and α are fitted parameters and x is particle size. The p-order model (Eq. (2.1.8)) becomes, therefore,

$$C_i(t) = C_i(0)\exp(-Kx^{\alpha}t^{p_i}) \qquad (2.1.8b)$$

2.1.3.3 Application to Heterogeneous Materials

The theory so-far described and the bulk of the experimental testing of the models has been for homogeneous materials. For present purposes it is necessary to extend to heterogeneous materials, and in particular to be able to describe each mineral individually.

The literature on heterogeneous materials is conspicuously sparce. Fuerstenau and Sullivan[38] have reported an investigation of grinding of mixtures of quartz and limestone. Although energy oriented, this work shows that for the same grind time, individually or mixed, both quartz and limestone produce their own characteristic size moduli in the Schuhmann Plot. Intuitively, from the plots displayed in their report, it is observed that the rate of breakage of the various mixtures is a weighted result of the rates of breakage of the quartz and limestone individually.

Heyes et al.[39] have reported experimental rates of breakage of galena, marmatite, chalcopyrite and quartz. These minerals were ground in a small wet rod mill. The environment grinding media was calcite. The report suggested that individually, the rate of breakage of the minerals is a function of the flow rate.

Recently, Gardner and Rogers[36] reported a two-component treatment for materials (coal and iron ore) displaying 'abnormal' behaviour in the sense of deviation from first-order kinetics, especially at the coarser sizes. Recognizing that the ore is composed of at least two principal components, one hard and one soft, a simple solution was to treat the non-first order as the sum of two first order equations. (This approach resembles the fitting technique applied by Kelsall to flotation kinetics.[40]) The general two-component equation of grinding proposed is the following:

$$w_i(t) = \sum_{j=1}^{i} a_{Aij} \exp(-S_{Aj}t) + \sum_{j=1}^{i} a_{Bij} \exp(-S_{Bj}t) \qquad (2.1.10)$$

where A and B denote components;

a_{Aij} and a_{Bij} are the coefficients of the Reid solution to the general equation of grinding, Equations (2.1.3a).

Remenyi[24] discusses quite extensively the mechanistic behaviour of mixtures on grinding. An interesting observation from laboratory studies was that soft minerals can be protected (buffered) by harder particles. This may have been observed in full size mills as well.[41] In addition, it was emphasized that the grinding kinetics of the individual components depended on the particular mixture under observation.

Tanaka and Selby[24] extended their approach described previously to binary mixtures. This approach appears useful in modelling the grinding of heterogeneous materials. The equation proposed for grinding a binary mixture is of the following form:

$$C_i(t) = r \exp(- K_{(1)} x^{\alpha} t^{p_i}) + (1 - r) \exp(- K_{(2)} x^{\alpha} t^{p_i}) \qquad (2.1.11)$$

where r is the mass fraction of material (1);

$K_{(1)}$ and $K_{(2)}$ are the rate of breakage of materials (1) and (2), respectively. Dimensions: $\text{size}^{-\alpha}.\text{time}^{-\beta}$.

The approach of Gardner and Rogers and Tanaka and Selby models the overall breakage directly. In principle, separate equations can be written for each component and the component breakage followed with the overall obtained at the end by summation. Cameron et al.[22] reported essentially this approach. The model was the full mass-size balance model. The complexity is illustrated by the fact that a 'reasonable' breakage function had to be assumed and S(x) obtained by back-calculation. Lynch[42.a] reports a similar procedure.

In the present case, the p-order model will be applied to each mineral. This can be written

$$C_{m,i}(t) = C_{m,i}(0) \exp \{- b_{m,i} t^{p_{m,i}}\} \qquad (2.1.12)$$

where the additional m subscript means each parameter is defined for each component, or mineral, individually.

2.1.4 Batch to Continuous Model

Not only has the bulk of the theory and the test work considered homogeneous materials, but also it has considered batch grinding, defined by a single time. In a continuous mill there is a distribution of residence times (or RTD).

The form of the RTD expresses the degree of mixing of the particles. The limits are: plug flow (degree of mixing = 0) and fully mixed (degree of mixing = 1). It is claimed that short mills, such as those in mineral processing, work close to fully mixed while the large tube mills common in the cement industry operate closer to the plug flow condition.[20,37] By measuring the RTD and knowing the breakage function, the selection function can be fitted to plant data. This is one approach and is, for instance, currently being used by the GRAAIM*, Laval University.[43] The breakage function is determined from laboratory batch grinds and is taken to be a unique function.

Several objections can be raised, particularly with regard to the RTD. Generally, this is measured by a tagged water or solids impulse technique. In the former, the equivalence of water and solids RTD is assumed and in the latter, such vexing possibilities as a different RTD for each size and even density component are important considerations.[39]

An analytical method to fit the RTD measured in the plant is to divide the mill into ideal tanks in series. These tanks can be any

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combination of plug flow and fully mixed reactors. The mean residence time of the real mill is split into the residence times in each of the tanks in the series.[43] The method is widely used in grinding simulation.[20,44,45] The fully-mixed grinding model is given by the following equation:

$$C_i(\tau) = C_i(0)/(1 + b_i \tau^{p_i}) \qquad (2.1.13)$$

Applying batch derived grinding data to the continuous mill has some obvious attractions. The simplest approach is to assume plug flow and replace t by τ in Equation (2.1.12), where

$$\tau = \frac{\text{volumetric ball mill holdup}}{\text{volumetric flow rate to mill}} = \frac{\text{BMH}}{\text{VF}} \qquad (2.1.14)$$

There is a potential problem with scaling. Following the suggestion of Olsen and Krogh[46], an empirical correction factor fitted to plant data is included. Equation (2.1.12) then becomes

$$C_{m,i}(\tau) = C_{m,i}(0) \exp\{- Fg_m\, b_{m,i}\, \tau^{p_{m,i}}\} \qquad (2.1.15)$$

where Fg_m is a plant data fitted parameter determined for each mineral.

The instantaneous rate-of-breakage, $\overline{k}_{m,i}$ is calculated with the following equation:

$$\bar{k}_{m,i} = Fg_m \, b_{m,i} \, \tau^{p_{m,i}-1} \qquad (2.1.16)$$

Furuya, Nakajima and Tanaka[37] have proposed a similar model of continuous grinding based on laboratory derived parameters. This model accounts for the degree of mixing and can be written:

$$C_i(\tau) = C_i(0) \exp \{- K(1 - mix)x^{\alpha}\tau\}/(1 + mix\ K\ x^{\alpha}\tau) \qquad .....(2.1.17)$$

where $C_i(\tau)$ and $C_i(0)$ are cum. weight fractions after τ time of grinding and feed, respectively.

K is a constant appearing in the selection function; units: $size^{-\alpha}\ time^{-1}$.

mix is the degree of mixing (mix = 0 for plug flow and mix = 1 for fully mixed flow conditions).

x is particle size.

α is a fitting constant.

τ is mean residence time.

Their analysis of closed grinding circuit (with perfect classification) lead to the useful conclusion that the product size distribution is relatively insensitive to mixing compared with open circuit, making the present assumption of plug flow less restrictive.[32] It is interesting to compare Equation (2.1.15) and (2.1.17); equating both equations yields:

$$\exp\{-Fg\, b_i\, \tau^{p_i}\} = \exp\{-K(1-mix)x^{\alpha}\tau\}/(1 + mix\, K\, x^{\alpha}\tau) \quad .....(2.1.18)$$

Using Equation (2.1.8) in (2.1.18) and Tanaka's Equation (2.1.11),

$$\exp\{-Fg\, b_i\, \tau^{p_i}\} = \exp\{-b_i(1-mix)\tau^{p_i}\}/(1 + mix\, b_i\tau^{p_i}) \quad .....(2.1.19)$$

Finally, solving for Fg yields:

$$Fg = \frac{(1-mix)}{\ln(1 + mix\, b_i\tau^{p_i})} \quad (2.1.20)$$

This can be generalized to consider each mineral and even each particle size individually.

The known parameters in Equation (2.1.20) (using lab and plant data) are: Fg and τ (plant fitted parameters) and b_i and p_i (lab data). It is readily noticed that mix cannot be solved directly, requiring a trial and error technique.

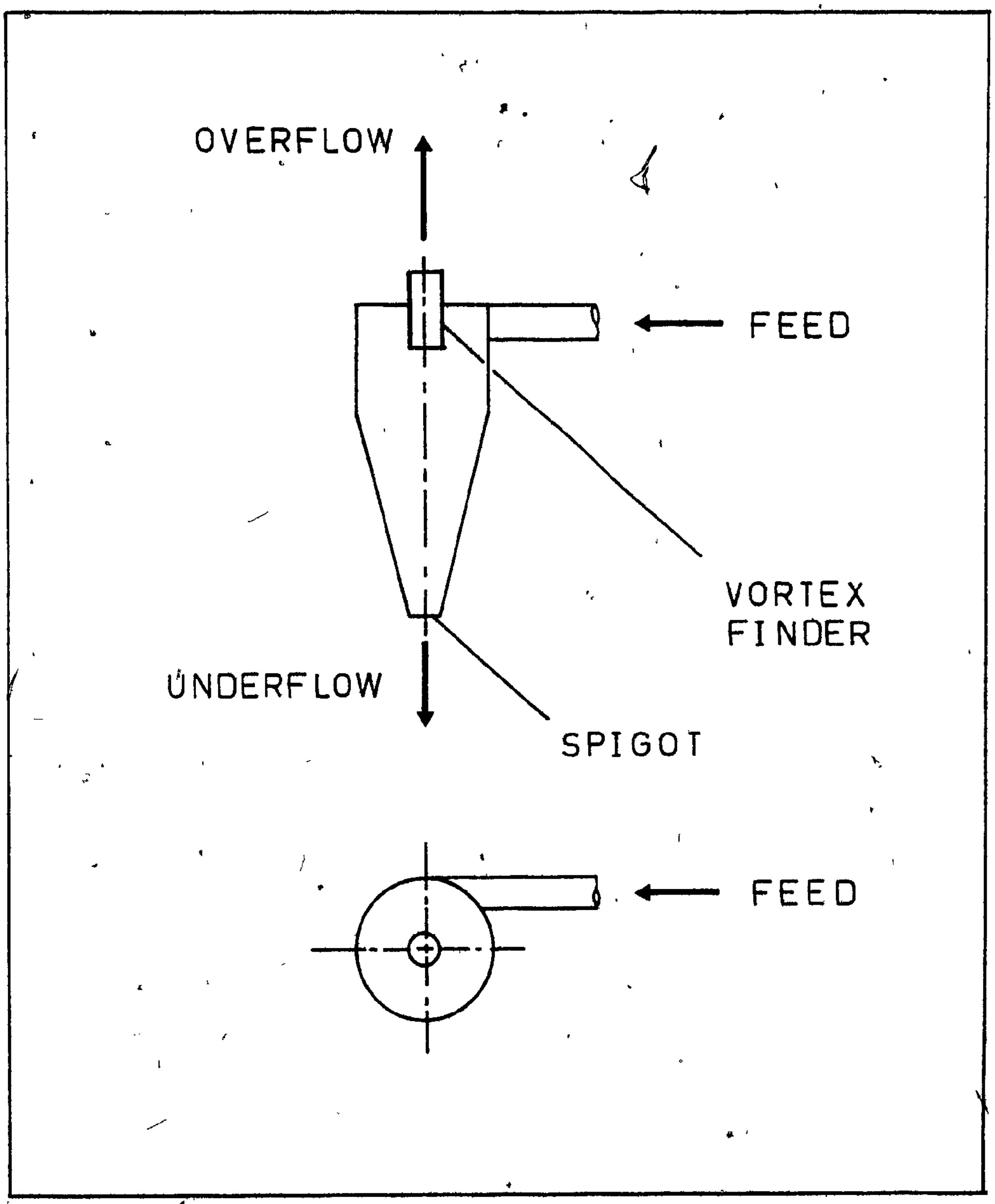
2.2 Classification

Classification in the No. 3 closed grinding circuit at Pine Point is performed by a cluster of five 50.8 cm (20") hydrocyclones (or cyclones).

Figure 2.2 is a standard cyclone design showing the tangential feed inlet, the vortex finder (overflow or fines outlet) and the spigot (underflow or sands outlet).

FIGURE 2.2

Design of the cyclone.


OVERFLOW
FEED
VORTEX
FINDER
UNDERFLOW
SPIGOT
FEED

The operating principle of the cyclone is rather simple. In practice, however, its performance is affected by many variables. Very briefly, the following is an explanation of the principle of operation of the cyclone:

A diluted slurry is pumped at a given pressure to the cyclone unit or to a head tank which feeds the cyclone. The slurry enters the cyclone tangentially and the pressure energy is transformed to centrifugal energy. The slurry now follows the shape of the cylindrical section where a falling downstream spiral is induced. The spiral continues falling into the conical section until arriving at the cyclone underflow outlet. This orifice imposes a constraint on the falling stream leaving the cyclone, thus an inner upstream spiral builds until reaching the upper overflow outlet where it leaves freely. Steady state conditions are achieved and classification takes place due to the competing forces induced inside the cyclone. These forces are: centrifugal forces depending upon the mass of the particle and tending to draw material to the underflow; and drag forces depending upon the surface area of a particle and tending to draw material to the overflow.

The result of this force competition is that heavy particles leave the cyclone by the underflow and the light particles by the overflow outlet.

In the above discussion of classification, particle mass rather than size was emphasized. For homogeneous materials, mass and size can be interchanged and classification analysed in terms of particle size alone.

A quite different picture emerges when the cyclone is used to classify heterogeneous materials. In this case, no simplification to a dependence on particle size alone is possible. This consideration becomes particularly important metallurgically when locked particles are subjected to classification.

2.2.1 The Cyclone Performance Curve - Overall

This curve is obtained by plotting the selectivity index Y_i against d, the geometric size of screen openings. In mathematical form Y_i is given by the following equation:

$$Y_i = \frac{(\alpha - 1)b_i}{(\alpha - 1)b_i + d_i} = \frac{b_i}{b_i + \frac{1}{\alpha - 1}d_i} \qquad (2.2.1)$$

where α is the ratio of cyclone feed to cyclone overflow.

b_i and d_i are mass fraction of size i of underflow and overflow streams, respectively.

2.2.2 The Cyclone Performance Curve - Mineral by Mineral

This is a plot of $Y_{m,i}$ against d, where m denotes the mineral species under consideration. The selectivity index $Y_{m,i}$ is found by means of the following equation:

$$Y_{m,i} = \frac{(\alpha - 1)b_i b_{m,i}}{(\alpha - 1)b_i b_{m,i} + d_i d_{m,i}}$$

$$= \frac{b_i b_{m,i}}{b_i b_{m,i} + \frac{1}{\alpha - 1} d_i d_{m,i}} \quad (2.2.2)$$

The terms $b_{m,i}$ and $d_{m,i}$ are chemical assays of mineral m of fractions of size i in the underflow and overflow, respectively.

2.2.3 Corrected Performance Curves

In order to account for the loss of efficiency represented by the short-circuiting of fine particles to the underflow, a reduced or corrected performance curve is obtained by plotting the corrected selectivity index Y'_i against particle size d. For the overall the correction is as follows:

$$Y'_i = \frac{Y_i - a}{1 - a} \quad (2.2.3)$$

where Y'_i is the corrected selectivity index.
a is the short-circuited fraction to the underflow.

Equation (2.2.3) can be written for each mineral species, becoming:

$$Y'_{m,i} = \frac{Y_{m,i} - a_m}{1 - a_m} \quad (2.2.4)$$

where $Y'_{m,i}$ is the classification index of mineral m.
a_m is the short-circuited fraction of mineral m to the underflow.

2.2.4 Cyclone Models

Depending on the flexibility desired, there are in general three approaches to cyclone modelling:

a) To determine the selectivity indices $Y_{m,i}$ from plant data and use them directly as a matrix of values.

b) To use the selectivity indices found in a) to derive a generalized single equation of classification.[2,41]

c) To couple b) with full scale testing programs on the ore of interest and to find regression equations which account for operating and design variables.[42,6]

The first is a trivial approach; the remaining two are discussed.

2.2.4.1 The General Equation of Classification

For ores containing more than one mineral species, the cyclone performance can be characterized by a single equation which relates $d_{50(C)m}$, the corrected cut-size of each mineral m, to its specific gravity.[2,49] The derivation of this general relationship is as follows: firstly, the mineral by mineral selectivity indices $Y_{m,i}$ are corrected for short-circuiting of fines to the underflow. The equations utilized are Equations (2.2.2) and (2.2.4):

$$Y_{m,i} = \frac{b_i b_{m,i}}{b_i b_{m,i} + \frac{1}{(1-\alpha)} d_i d_{m,i}} \tag{2.2.2}$$

and

$$Y'_{m,i} = \frac{Y_{m,i} - a_m}{1 - a_m} \tag{2.2.4}$$

Secondly, the classification indices $Y'_{m,i}$ are related to the geometric mean particle size d. The equation is of the form[48]:

$$Y'_{m,i} = 1. - \exp\{-0.693(d/d_{50(C)m})^{n_m}\} \qquad (2.2.5)$$

The parameters $d_{50(C)m}$ and n_m of Equation (2.2.5) are the corrected cut-size, and sharpness of classification, respectively, and are estimated by a least squares technique.

For regression analysis, Equation (2.2.5) can be expressed as follows:

$$\ln \ln\left(\frac{1}{1 - Y'_{m,i}}\right) = n_m \ln(x) + \ln 2 \qquad (2.2.5a)$$

where $x = d/d_{50(C)m}$ (2.2.6)

Finally, the estimated $d_{50(C)m}$ values from regression analysis are further correlated to the specific gravity of the various minerals. The relationship is of the following form: [41,49]

$$\ln d_{50(C)m} = -K_1 \ln(\rho_m - \rho_\ell) + K_2 \qquad (2.2.7)$$

where ρ_m and ρ_ℓ are the specific gravities of the mineral m and liquid (water), respectively.

K_1 and K_2 are the slope and intercept, respectively.

From hydrodynamic theory, K_1 equals 0.5, 0.62 and 1.0 for laminar, intermediate and turbulent flow regimes, respectively.

2.2.4.2 Model Including Operating and Design Variables

This approach has been principally developed by Lynch and Rao[50], although a recent model has been reported by Plitt[51] and modelling work is now in progress at GRAAIM, Laval University.[43]

The model by Lynch is empirically based and the mathematical relationships are found by statistical analysis on experimental data obtained from full scale test rigs. These tests were performed using limestone. The design variables in the model are the vortex finder, spigot and inlet diameters, and the operating variables are the flow rate, percent solids and size distribution of the solid particles in the pulp.

This is a mechanistic model which is based on concepts of $d_{50(C)}$ and the corrected performance curve. The series of equations which describe the cyclone model are: (1) pressure-throughput relationship; (2) water split ratio; and (3) classification size, ($d_{50(C)}$).

Pressure-Throughput Relationship

A general equation relating pressure, inlet diameter and changes in size distribution of the cyclone feed is the following:

$$Q = KL_1 VF^{0.68} \, Inlet^{0.85} \, Spig^{0.16} \, P^{0.49} (-\,53\ \mu m)^{-0.35} \qquad .....(2.2.8)$$

where Q - pulp flow rate to the cyclone feed, lt/min

VF - vortex finder diameter, cm

Inlet - inlet diameter, cm

Spig - spigot diameter, cm

P - pressure in the cyclone feed, KPa

(- 53 μm) - percent by wt passing 270 mesh

KL_1 - constant

Water Split Ratio, R_f

The variables affecting the R_f ratio were feed water flow rate, WF and spigot diameter, spig. The equation is of the following form:

$$R_f = KL_2 \frac{spig}{WF} + \frac{KL_3}{WF} + KL_4 \qquad (2.2.9)$$

For limestone, KL_2, KL_3, and KL_4 were found to be 193, - 271.6 and - 1.61, respectively. WF is the water flow rate in the cyclone feed in tonne/hr.

Corrected Cut-Size, $d_{50(C)}$

The $d_{50(C)}$ related to operating and design variables is of the following form:

$$\log d_{50(C)} = KL_5\, VF + KL_6\, Spig + KL_7\, Inlet + KL_8 \,.\, FPS$$

$$+ KL_9\, Q + KL_{10} \qquad .....(2.2.10)$$

where VF - vortex finder diameter, cm

Spig - spigot diameter, cm

Inlet	-	inlet diameter, cm
FPS	-	percent solids of pulp in the cyclone feed
Q	-	flowrate of pulp in the inlet, lt/min
KL_5 to KL_{10}	-	regression constants

The regression constants KL_5 to KL_{10} for the limestone tests were:

$$KL_5 = 0.0400 \qquad KL_8 = 0.0299$$
$$KL_6 = -0.0576 \qquad KL_9 = -0.00005$$
$$KL_7 = 0.0366 \qquad KL_{10} = 0.0806$$

In applying the models, the constants KL_1, KL_4 and KL_{10} are usually fitted to the plant data at hand, the remaining constants being as defined.

An aspect of considerable interest is to combine the generalized classification model, Equation (2.2.7) with the Lynch model, Equations (2.2.9) and (2.2.10). The strategy is to use Equation (2.2.10) to find $d_{50(C)}$ for calcite/dolomite (the most abundant mineral, ∿ 58% in the cyclone feed). Assuming that K_1 of Equation (2.2.7) remains constant the $d_{50(C)}$ for PbS, ZnS and FeS_2 are calculated. Finally, back-calculation of $Y_{m,i}$ is readily performed.

2.3 Data Adjustment

It is frequently the situation that sufficient data is taken in a sampling campaign to calculate mass flow rates by more than one route. An example would be a mass flow calculation using either sizing data or chemical assays. This overabundance of data is sometimes called 'redundant' in the sense that it is more than is required to calculate a mass flow. As can be expected, different calculation routes will lead to different mass flow estimates. Hopefully, the differences are small, but they reflect the difficulties in sampling and measurement.

There are several reasons why adjusting the data to be consistent with the 'best estimate' mass flow is desirable. Firstly, in model building it is usually necessary to determine empirical constants which can be sensitive to the data base used.[52,53] At the same time, correlating model predictions with the original data is difficult as the model, clearly, will not allow inconsistencies. A third reason although not of direct interest here, is that by observing those data which receive the most adjustment, insight is gained into the accuracy of instrument readings or analytical techniques.[52]

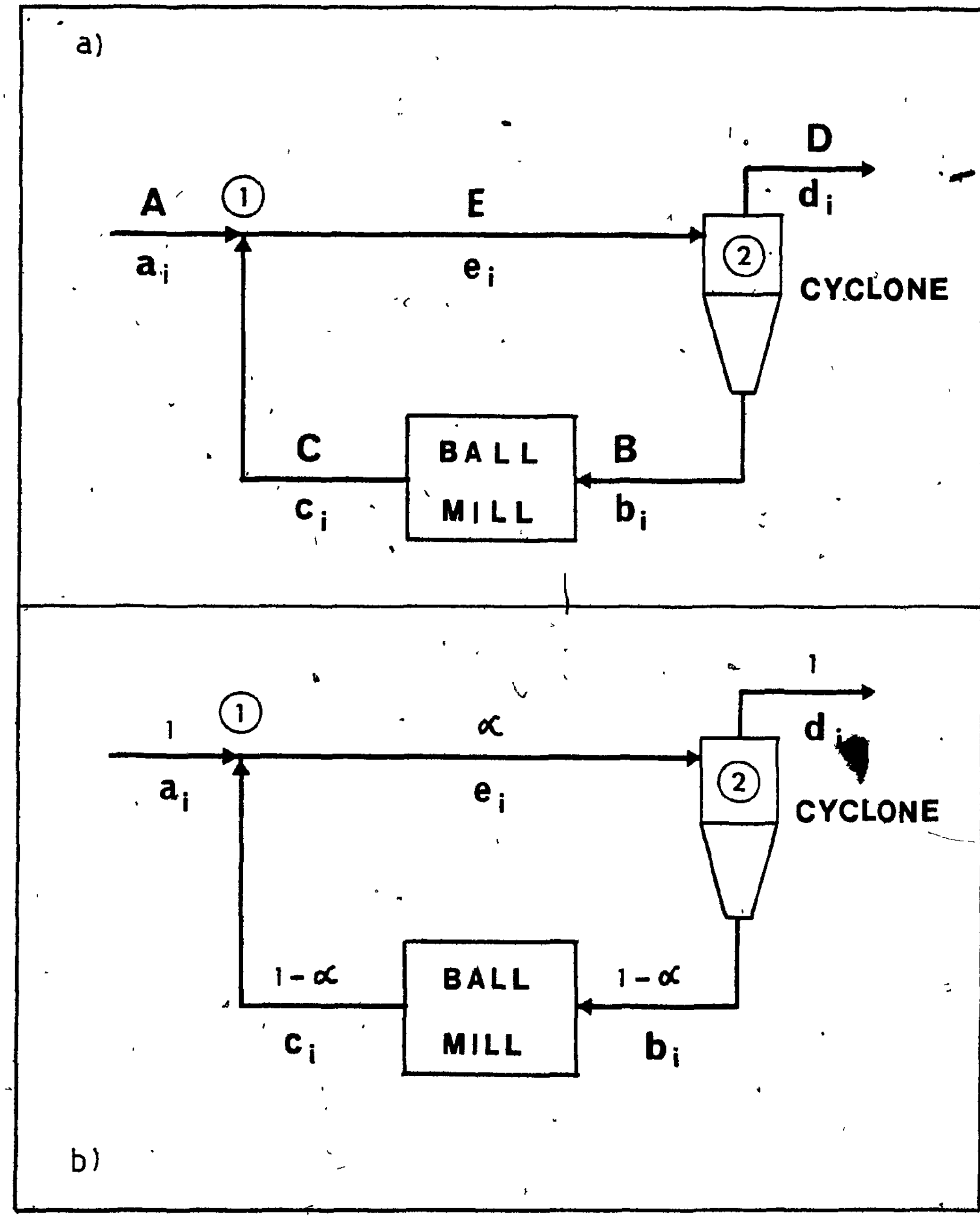
A growing crop of papers have been devoted in recent years to adjustment techniques for plant data.[52,55] The method adopted here is based on that described by Lynch.[42b] Data adjustment in the present case is required both for plant data and the laboratory grinding data. The latter is handled differently and is described in Section 2.3.5.

2.3.1 Best-Fit Mass Flow Calculations

This technique is based on minimisation of the sum of squares of residual errors, arising from sampling and screening measurements. Figure 2.3 shows the closed grinding circuit. The top section shows the mass flow rates and the size assays. Below, in the same figure,

FIGURE 2.3

Closed grinding circuit. a) non-rationalized flow rates; b) rationalized flow rates.


a)
A
①
E
D
a_i
e_i
d_i
②
CYCLONE
C
BALL
MILL
B
c_i
b_i
1
①
∝
1
a_i
e_i
d_i
②
CYCLONE
1 − ∝
BALL
MILL
1 − ∝
c_i
b_i
b)

is shown the circuit with the mass flow rates rationalized (α and (α - 1) are a measurement of the circulating load in the circuit). Mass balance around both nodes 1 and 2 yields:

$$\Delta_{(1)i} = - a_i - (\alpha - 1)c_i + \alpha e_i$$

$$= \alpha(e_i - c_i) + (c_i - a_i) \qquad (2.3.1)$$

$$\Delta_{(2)i} = - d_i - (\alpha - 1)b_i + \alpha e_i$$

$$= \alpha(e_i - b_i) + (b_i - d_i) \qquad (2.3.2)$$

where $\Delta_{(1)i}$ - residual error in node 1 of screen fraction i

$\Delta_{(2)i}$ - residual error in node 2 of screen fraction i

a_i, b_i, c_i, d_i, e_i - are unadjusted size assays (see nomenclature in Table 2.1)

The sum of squares of residual errors is given by

$$SS = \sum_i (\Delta^2_{(1)i} + \Delta^2_{(2)i}) \qquad (2.3.3)$$

Solving the partial derivative with respect to α and equating to zero, yields the best-fit estimate, $\bar{\alpha}$. The solution is the following:

TABLE 2.1 Nomenclature

	Screen Analysis, %		Chemical Analysis, % Overall		Chemical Analysis, % Size-By-Size	
Stream	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
circuit feed	a_i	$\bar{a}_i$	A_m	$\bar{A}_m$	$a_{m,i}$	$\bar{a}_{m,i}$
cyclone feed	e_i	$\bar{e}_i$	E_m	$\bar{E}_m$	$e_{m,i}$	$\bar{e}_{m,i}$
cyclone overflow	d_i	$\bar{d}_i$	D_m	$\bar{D}_m$	$d_{m,i}$	$\bar{d}_{m,i}$
cyclone underflow	b_i	$\bar{b}_i$	B_m	$\bar{B}_m$	$b_{m,i}$	$\bar{b}_{m,i}$
ball mill discharge	c_i	$\bar{c}_i$	C_m	$\bar{C}_m$	$c_{m,i}$	$\bar{c}_{m,i}$

where: i - screen number
m - metal (Pb, Zn, or Fe)

$$\bar{\alpha} = \frac{-\sum_i (e_i - c_i)(c_i - a_i) + (e_i - b_i)(b_i - d_i)}{\sum_i (e_i - c_i)^2 + (e_i - b_i)^2} \qquad (2.3.4)$$

2.3.2 Size Assays Adjustment

In order to have size assays consistent with the best-fit circulating load $\bar{\alpha}$ given by Equation (2.3.4), minimisation of the sum of squares of screening residual errors is necessary. This sum of squares is given by the following equation:

$$SS_i = \sum_i (\Delta^2 a_i + \Delta^2 b_i + \Delta^2 c_i + \Delta^2 d_i + \Delta^2 e_i) \qquad (2.3.5)$$

Allowing for screening errors and mass balancing around nodes 1 and 2 gives:

$$\bar{\alpha}(e_i - \Delta e_i) - (a_i - \Delta a_i) - (\bar{\alpha} - 1)(c_i - \Delta c_i) = 0 \qquad (2.3.6)$$

$$\bar{\alpha}(e_i - \Delta e_i) - (d_i - \Delta d_i) - (\bar{\alpha} - 1)(b_i - \Delta b_i) = 0 \qquad (2.3.7)$$

The constraint equations are:

$$\Delta_{(1)i} - \bar{\alpha}\Delta e_i + \Delta a_i + (\bar{\alpha} - 1)\Delta c_i = 0 \qquad (2.3.8)$$

$$\Delta_{(2)i} - \bar{\alpha}\, e_i + \Delta d_i + (\bar{\alpha} - 1)\Delta b_i = 0 \qquad (2.3.9)$$

To simplify minimisation in solving the partial derivatives, the Lagrange technique is used. This technique consists of adding to the sum of squares, the constraints multiplied by a Lagrangian multiplier. That is:

$$S_{m,i} = SS_i + \sum_i \lambda_i \cdot \text{constraint } i \qquad (2.3.10)$$

In this case:

$$S_{m,i} = SS_i + 2\lambda_{(1)i}\{\Delta_{(1)i} - \bar{\alpha}\Delta e_i + \Delta a_i + (\bar{\alpha} - 1)\Delta c_i\}$$

$$+ 2\lambda_{(2)i}\{\Delta_{(2)i} - \bar{\alpha}\Delta e_i + \Delta d_i + (\bar{\alpha} - 1)\Delta b_i\} \qquad (2.3.11)$$

Derivatives with respect to residuals yield for each i:

$$\Delta a_i = -\lambda_{(1)i} \qquad (2.3.12)$$

$$\Delta b_i = -\lambda_{(2)i} \qquad (2.3.13)$$

$$\Delta c_i = -\lambda_{(1)i}\{\bar{\alpha} - 1\} \qquad (2.3.14)$$

$$\Delta d_i = -\lambda_{(2)i} \qquad (2.3.15)$$

$$\Delta e_i = \bar{\alpha}\{\lambda_{(1)i} + \lambda_{(2)i}\} \qquad (2.3.16)$$

Similarly, for $\Delta_{(1)i}$ and $\Delta_{(2)i}$, partially differentiating S_m with respect to $\lambda_{(1)i}$ and $\lambda_{(2)i}$, and equating to zero, yields:

$$\Delta_{(1)i} = \lambda_{(1)i} \{\bar{\alpha}^2 + 1 + (\bar{\alpha} - 1)^2\} + \lambda_{(2)i} \bar{\alpha}^2 \qquad (2.3.17)$$

$$\Delta_{(2)i} = \lambda_{(1)i} \bar{\alpha}^2 + \lambda_{(2)i} \{\bar{\alpha}^2 + 1 + (\bar{\alpha} - 1)^2\} \qquad (2.3.18)$$

The above Equations (2.3.17) and (2.3.18) are a system of linear simultaneous equations in $\lambda_{(1)i}$ and $\lambda_{(2)i}$. $\Delta_{(1)i}$ and $\Delta_{(2)i}$ are determined from the raw data using Equations (2.3.1) and (2.3.2). Finally, each size assay is adjusted using: adjusted = observed - residual.

2.3.3 Overall Chemical Assays Adjustment

An extension of the adjustment technique described above is to adjust the overall chemical assays of each mineral present in the closed circuit streams.

To illustrate the technique, the next section deals in summarized form with the overall adjustment of lead (Pb).

Constraints

Node 1 $$\bar{\alpha} E_{Pb} = (\bar{\alpha} - 1)C_{Pb} + A_{Pb} \qquad (2.3.19)$$

Node 2 $$\bar{\alpha} E_{Pb} = (\bar{\alpha} - 1)B_{Pb} + D_{Pb} \qquad (2.3.20)$$

Node 3 $$B_{Pb} = C_{Pb} \qquad (2.3.21)$$

Node 4 $$A_{Pb} = D_{Pb} \qquad (2.3.22)$$

where A_{Pb} is overall Pb assay of RMD stream

B_{Pb} is overall Pb assay of CUF stream

C_{Pb} is overall Pb assay of BMD stream

D_{Pb} is overall Pb assay of COF stream

E_{Pb} is overall Pb assay of CF stream

and Nodes 3 and 4 are ball mill and entire circuit, respectively.

Equations of Residual Errors

$$\Delta_{(1)Pb} = (\bar{\alpha} - 1)C_{Pb} + A_{Pb} - \bar{\alpha} E_{Pb} \quad (2.3.23)$$

$$\Delta_{(2)Pb} = (\bar{\alpha} - 1)B_{Pb} + D_{Pb} - \bar{\alpha} E_{Pb} \quad (2.3.24)$$

$$\Delta_{(3)Pb} = C_{Pb} - B_{Pb} \quad (2.3.25)$$

$$\Delta_{(4)Pb} = D_{Pb} - A_{Pb} \quad (2.3.26)$$

where $\Delta_{(1)Pb}$ to $\Delta_{(4)Pb}$ are the overall lead (Pb) residuals (mass units) of streams 1 to 4, respectively.

Sum of Squares of Residuals

$$SS_{Pb} = \Delta^2_{(1)Pb} + \Delta^2_{(2)Pb} + \Delta^2_{(3)Pb} + \Delta^2_{(4)Pb} \quad (2.3.27)$$

The Lagrangian

$$\ell = SS_{Pb} + 2\lambda_{(1)Pb}\{\Delta_{(1)Pb} - (\bar{\alpha} - 1)\Delta C_{Pb} - \Delta A_{Pb} + \bar{\alpha}\,\Delta E_{Pb}\}$$

$$+ 2\lambda_{(2)Pb}\{\Delta_{(2)Pb} - (\bar{\alpha} - 1)\Delta B_{Pb} - \Delta D_{Pb} + \bar{\alpha}\,\Delta E_{Pb}\}$$

$$+ 2\lambda_{(3)Pb}\{\Delta_{(3)Pb} - \Delta C_{Pb} + \Delta B_{Pb}\}$$

$$+ 2\lambda_{(4)Pb}\{\Delta_{(4)Pb} - \Delta D_{Pb} + \Delta A_{Pb}\} \quad \ldots\ldots(2.3.28)$$

Partial Derivatives to Solve for Residuals and Lagrangian Multipliers

$$\frac{\partial \ell}{\partial \Delta A_{Pb}} = 2\Delta A_{Pb} - 2\lambda_{(1)Pb} + 2\lambda_{(4)Pb} = 0$$

$$\therefore \quad \Delta A_{Pb} = \lambda_{(1)Pb} - \lambda_{(4)Pb} \quad (2.3.29a)$$

$$\frac{\partial \ell}{\partial \Delta B_{Pb}} = 2\Delta B_{Pb} - 2\lambda_{(2)Pb}(\bar{\alpha} - 1) + 2\lambda_{(3)Pb} = 0$$

$$\therefore \quad \Delta B_{Pb} = \lambda_{(2)Pb}(\bar{\alpha} - 1) - \lambda_{(3)Pb} \quad (2.3.29b)$$

$$\frac{\partial \ell}{\partial \Delta C_{Pb}} = 2\Delta C_{Pb} - \lambda_{(1)Pb}(\bar{\alpha} - 1) - \lambda_{(3)Pb} = 0$$

$$\therefore \quad \Delta C_{Pb} = \lambda_{(1)Pb}(\bar{\alpha} - 1) + \lambda_{(3)Pb} \quad (2.3.29c)$$

$$\frac{\partial \ell}{\partial \Delta D_{Pb}} = 2\Delta D_{Pb} - \lambda_{(2)Pb} - \lambda_{(4)Pb} = 0$$

$$\therefore \quad \Delta D_{Pb} = \lambda_{(2)Pb} + \lambda_{(4)Pb} \quad (2.3.29d)$$

$$\frac{\partial \ell}{\partial \Delta E_{Pb}} = 2\Delta E_{Pb} + \lambda_{(1)Pb}\,\bar{\alpha} + \lambda_{(2)Pb}\,\bar{\alpha} = 0$$

$$\therefore \quad \Delta E_{Pb} = -\bar{\alpha}(\lambda_{(1)Pb} + \lambda_{(2)Pb}) \qquad (2.3.29e)$$

$$\frac{\partial \ell}{\partial \lambda_{(1)Pb}} = 2\{\Delta_{(1)Pb} - (\bar{\alpha} - 1)\Delta C_{Pb} - \Delta A_{Pb} + \bar{\alpha}\Delta E_{Pb}\}$$

$$= 2\{\Delta_{(1)Pb} - (\bar{\alpha} - 1)^2\lambda_{(1)Pb} - \lambda_{(3)Pb}(\bar{\alpha} - 1) + \lambda_{(4)Pb}$$

$$- \lambda_{(1)Pb} - \bar{\alpha}^2(\lambda_{(1)Pb} + \lambda_{(2)Pb})\} = 0$$

$$\therefore \quad \Delta_{(1)Pb} = (\bar{\alpha} - 1)^2\lambda_{(1)Pb} + \lambda_{(3)Pb}(\bar{\alpha} - 1)$$

$$- \lambda_{(4)Pb} + \lambda_{(1)Pb} + \bar{\alpha}^2(\lambda_{(1)Pb} + \lambda_{(2)Pb}$$

.....(2.3.30a)

Similarly:

$$\Delta_{(2)Pb} = (\bar{\alpha} - 1)^2\lambda_{(2)Pb} + \lambda_{(3)Pb}(\bar{\alpha} - 1) + \lambda_{(2)Pb}$$

$$+ \lambda_{(4)Pb} + \alpha^2(\lambda_{(1)Pb} + \lambda_{(2)Pb}) \qquad (2.3.30b)$$

$$\Delta_{(3)Pb} = \lambda_{(1)Pb}(\bar{\alpha} - 1) + 2\lambda_{(3)Pb} - \lambda_{(2)Pb}(\bar{\alpha} - 1) \qquad (2.3.30c)$$

$$\Delta_{(4)Pb} = \lambda_{(2)Pb} + 2\lambda_{(4)Pb} - \lambda_{(1)Pb} \qquad (2.3.30d)$$

Gathering terms:

$$\Delta_{(1)Pb} = \lambda_{(1)Pb} \{(\bar{\alpha} - 1)^2 + 1 + \bar{\alpha}^2\} + \bar{\alpha}^2\lambda_{(2)Pb} + \lambda_{(3)Pb}(\bar{\alpha} - 1) - \lambda_{(4)Pb} \quad (2.3.31a)$$

$$\Delta_{(2)Pb} = \lambda_{(1)Pb}\,\bar{\alpha}^2 + \lambda_{(2)Pb} \{(\bar{\alpha} - 1)^2 + 1 + \bar{\alpha}^2\} - \lambda_{(3)Pb}(\bar{\alpha} - 1) + \lambda_{(4)Pb} \quad (2.3.31b)$$

$$\Delta_{(3)Pb} = \lambda_{(1)Pb}(\bar{\alpha} - 1) - \lambda_{(2)Pb}(\bar{\alpha} - 1) + 2\lambda_{(3)Pb} \quad (2.3.31c)$$

$$\Delta_{(4)Pb} = - \lambda_{(1)Pb} + \lambda_{(2)Pb} + 2\lambda_{(4)Pb} \quad (2.3.31d)$$

These simultaneous equations are solved to determine $\lambda_{(1)Pb}$, etc.

Finally, the equations of residuals (2.3.29) are used to adjust the overall chemical analysis as follows:

Adjusted = Observed - Residual

2.3.4 Size-By-Size Chemical Assay Adjustment

These assays are the last raw data to be adjusted in order to have overall and mineral by mineral self consistent mass balances in the entire circuit. This adjustment is made by first determining the mineral size frequency distributions from the measured assays and the adjusted size frequency, derived earlier.

After that, the mineral size frequency distributions were adjusted following the technique discussed in Section 2.3.2. However, in this case, mass balances and residual errors are given in terms of mineral mass units. Finally, knowing the adjusted overall chemical assay, the adjusted chemical size by size assay is derived from the adjusted mineral size frequency.

2.3.5 Laboratory Data Adjustment

For the particular case of the grinding experiments performed on the Pb-Zn ore, different mean chemical assays between samples were expected. This should be small but again reflects errors in sampling and measurement.

The unique objective of adjusting the size chemical assays is to have self consistent data between samples.

For each mineral, the adjustment was as follows:

1. Find the overall mineral units of each grind sample.
2. Determine the mineral units of each size fraction.
3. Determine the mean overall mineral units for the grind samples.
4. Adjust the mineral units of each size to agree with the mean mineral unit assay.

CHAPTER III

EXPERIMENTAL WORK

The experimental work entailed two principal efforts: to obtain a reliable mass-size balance of the Pine Point No. 3 circuit; and to develop a kinetic model of grinding to describe the No. 3 circuit ball mill using either plant or laboratory derived parameters.

Some procedures are common to both of these efforts and are described first.

3.1 Standard Experimental Procedures

3.1.1 Sampling

Sampling was performed in a spinning riffler device of the following characteristics:

a) wheel diameter: 60 cm

b) compartments: 12

c) wheel speed: 12 rpm (constant)

d) feeder: vibratory (variable speed)

The spinning riffler offers the advantage of supplying 12 samples from one bulk sample and has proven to be a reliable sampling device.(56) The accuracy of sampling was, nevertheless, tested and the mean, standard deviation and variance measured.

3.1.2 Screening

A $\sqrt{2}$ Tyler screen series was employed (see Table III:1, Appendix III, for specifications) and screening was performed on a

Ro-Tap. In order to determine the optimum time for dry screening on the Ro-Tap, a series of screening tests using silica as testing material was performed; cumulative weight percent finer as a function of time was measured. To overcome the agglomeration problem arising when samples having high slimes content are dry screened, a combined wet-dry screening procedure was adopted.[57] The following describes the screening sequence used:

a) Wet screening of approximately 100 g of material on the finest screen.

b) Filtering and drying the fine fraction at no more than 150°C.

c) Decanting and drying the coarse fraction at no more than 150°C.

d) Dry screening the coarse fraction in the Ro-Tap for 20 min.

e) Weighing the fine and coarse fractions.

f) Calculation of the size assays.

3.1.3 Chemical Analysis

The sized fractions for the plant survey and laboratory grinding tests were assayed for Pb, Zn and Fe using standard atomic absorption procedures (see Appendix II). With these assays and the stoichiometric factors for converting to mineral assays, the calcite-dolomite composition was calculated by difference.

3.1.4 Specific Gravity Determination

The specific gravity of the Pb-Zn ore was determined as follows:

a) Sampling in the spinning riffler to obtain a representative sample of approximately 300 g.

b) Pouring into a 500 ml glass graduate in which previously water was added to a definite mark (250 ml).

c) Degassing for 30 min. using an ultrasonic cleaner at approximately 40 KHz.

d) Measuring the displaced volume and calculation of the specific gravity.

3.2 Plant

The five streams shown in Figure 1.1 were sampled every 15 min. for two hours on two occasions at feed rates of 154.2 and 190.3 mtph. These samples were dried and screened at Pine Point for an initial assessment of reliability. The samples were then sent to McGill for complete size and chemical analysis. Pulp density was also measured; samples collected at the beginning, middle and end of the sampling campaign were combined and weighed, then dried and re-weighed and per cent solids calculated.

3.3 Laboratory

3.3.1 Silica

Silica experiments were performed principally to establish a suitable grinding procedure.

Pure silica (SiO_2) grains of 4 x 6 mesh size was the starting material for these experiments. To be further utilized, the silica was size reduced in a cone crusher. One sample of the crushing operation was separated for a grinding experiment. Seven more samples were synthetically prepared according to the requirements of feed particle size distribution defined below.

Table 3.1 is a summary of the variables investigated in this testing program. These variables are:

<u>Feed</u>:

<u>Natural</u>: Refers to the particle size distribution of the sample after crushing in the cone crusher.

<u>Synthetic 1</u>: Refers to the particle size distribution of samples built up with screened fractions. This particle size distribution is defined by the Schuhmann-Gaudin-Gates parameters α and k appearing in the equation: $y = 100(\frac{x}{k})^{\alpha}$;

where: $\alpha = 0.8$

$k = 650\ \mu m$

<u>Synthetic 2</u>: Refers to a typical rod mill discharge product particle size distribution.

<u>20 x 28#</u>: Refers to a single-size feed material of size -20 mesh to +28 mesh.

TABLE 3.1 Variables Investigated in the Grinding Test Work, PCT. V.F. is the Percentage of Voids or Interstitial Space Between Balls Filled with the Material to be Ground.

SILICA TESTS (DRY)

Experiments	Feed	Method	PCT. V.F.
1	natural	recycling	80%
2	synthetic 1	one-sample-at-a-time	80%
3	synthetic 1	recycling	80%
4	synthetic 1	recycling	100%
5	20 x 28#	recycling	100%
6	20 x 28#	recycling	80%
7	synthetic 2	recycling	100%
8	synthetic 2	recycling	100%

Pb-Zn ORE TESTS (WET)

Experiment	Method	PCT. V.F.	PCT. SOL. by VOL.	PCT. SOL. by Wt.
CUF	one-sample at-a-time	120%	42.13%	72 %
RMD	one-sample at-a-time	120%	42.13%	69.2%

Method:

Recycling: Refers to the method of grinding in which only one sample is used for all the grinding times; i.e. once the grinding time of a given sample is completed, the product is sampled for screen analysis. After screening all the material is returned to the mill for further grinding.

One-Sample-At-A-Time: This method consisted of preparing one sample for each grinding period of time. The samples were synthetically built up in such a way as to have identical particle size distribution and total mass.

3.3.2 Pb-Zn Ore

The Pb-Zn samples for grinding experiments were collected at the CUF (cyclone underflow) and RMD (rod mill discharge) at the end of the two hour sampling campaign at 154.2 mtph. The samples (∿ 30 Kg) were filtered and dried and sent in air-tight plastic containers to McGill University. Preparation of these samples for the grinding experiments was as follows:

a) Drying in the oven at no more than 150^{o}C.

b) Using the spinning riffler, the sample was split so as to obtain representative samples of approximately 1300 g each.

Table 3.1 shows the experimental conditions chosen for grinding the CUF and RMD materials. These batch grind tests were designed to replicate the large continuous operation in respect to pulp density, ball filling of the mill and charge of material[34] (Appendix III, Section III.2.2, contains the calculations). Table 3.2 summarizes the loading characteristics of both laboratory and plant ball mills. The grind times were for the CUF material, 2, 4, 6, 8, 10 and 12 min., and for RMD, 1, 2, 4, and 8 min.

TABLE 3.2 Comparison of Laboratory and Plant Grinding Mill Loading Characteristics

Quantity	Lab	Plant
% ball filling	42*	∿ 39**
% void filling	120	120**
size of ball, cm	2.54 (1")	7.62 (3")***
% of solids (v/v)	42.1	42.1****

* determined using 12% internal mill volume as voids (8)

** estimated from geometric considerations (see Appendix III)

*** nominal make-up size

**** as measured in plant

After completing each grind period, the mill was emptied using the least amount of water possible and the pulp dewatered using the filter and then dried at no more than 150°C. The dried samples were split in the spinning riffler and sized by the wet-dry screening procedure. The screened fractions were stored in envelopes and labelled for identification. Chemical analysis on each size fraction was performed for each grind time. The experimental data was finally used to determine the cumulative-basis first and p-order overall and mineral-by-mineral grinding kinetics.

CHAPTER IV

GRINDING CIRCUIT SIMULATION

As discussed in Chapter I, it is proposed to modify the existing circuit by including a Pb flotation stage on the ball mill discharge. In order to assess the effect of this circuit change, the first objective was to develop a simulator capable of describing the existing circuit. With this successfully achieved, the simulation can be extended with confidence to the proposed circuit.

The strategy adopted was to develop size-by-size, mineral-by-mineral models of the grinding, classification and flotation units. The p-order grinding model was selected and the kinetic parameters determined from laboratory batch tests. The grinding factor, Equation (2.1.14), was then estimated by fitting to the plant data.

The classification model considered individual mineral performance and was developed from plant data (after adjustment).

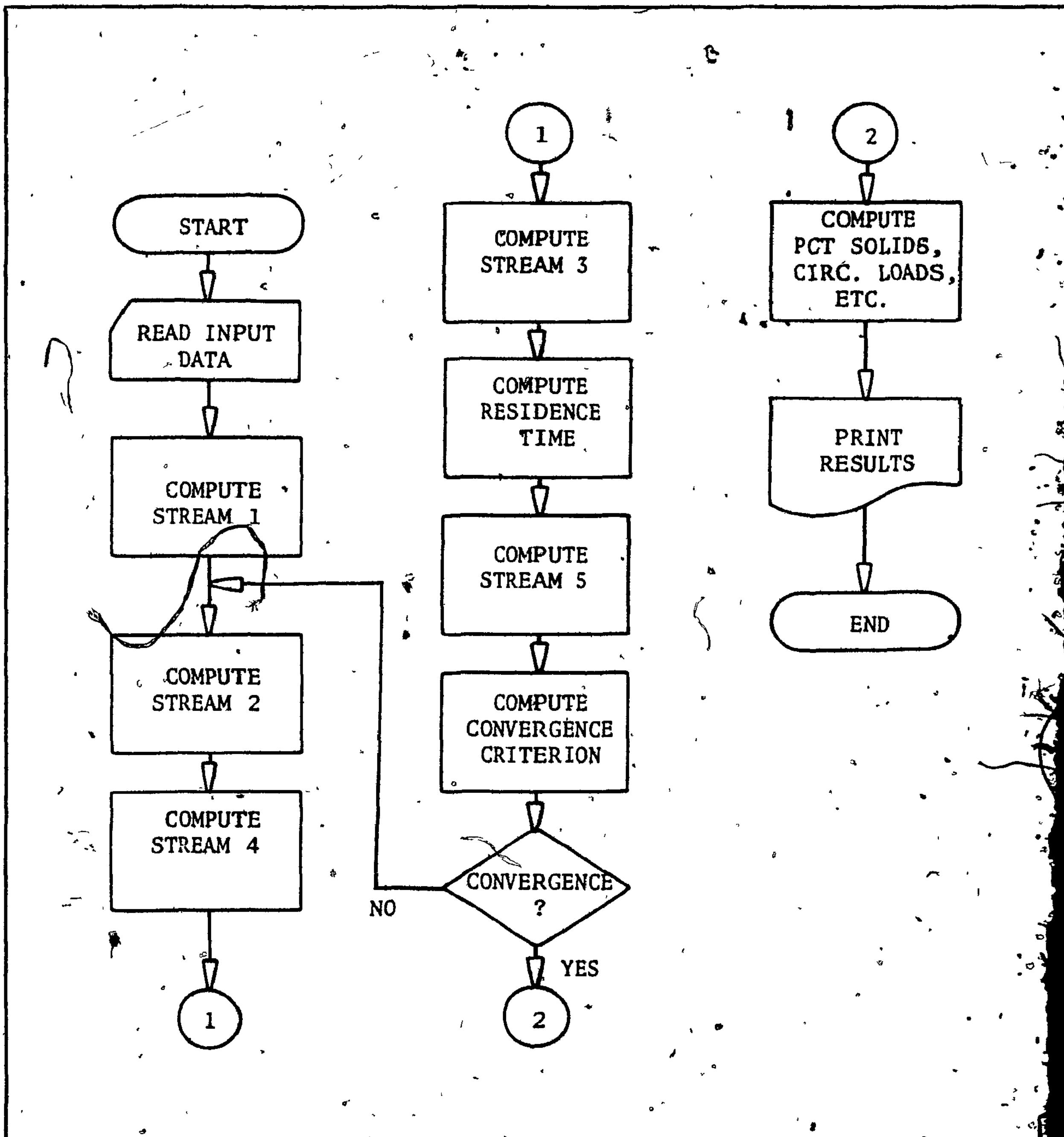
For the flotation stage, experiments were performed both at the Pine Point plant and McGill laboratories using ball mill discharge from the existing circuit and fresh ore samples; mineral size-recovery curves were determined.

4.1 Simulation of Actual Circuit (Mineral-by-Mineral)

The flow chart diagram of Figure 4.1 shows schematically the computer program developed to simulate the actual circuit configuration shown in Figure 1.1; Appendix V, Section V.1 shows the program.

FIGURE 4.1

Simplified flow chart diagram of computer program to simulate the actual closed grinding circuit.


START
READ INPUT DATA
COMPUTE STREAM 1
COMPUTE STREAM 2
COMPUTE STREAM 4
1
1
COMPUTE STREAM 3
COMPUTE RESIDENCE TIME
COMPUTE STREAM 5
COMPUTE CONVERGENCE CRITERION
CONVERGENCE ?
NO
YES
2
2
COMPUTE PCT SOLIDS, CIRC. LOADS, ETC.
PRINT RESULTS
END

This is an iterative program which accounts for dry solid and water mass flow rate balances around the circuit. The iterative process terminates when a finite difference between input and output mass flow rates is achieved. This is the steady state flow regime criterion, set at 0.1%.

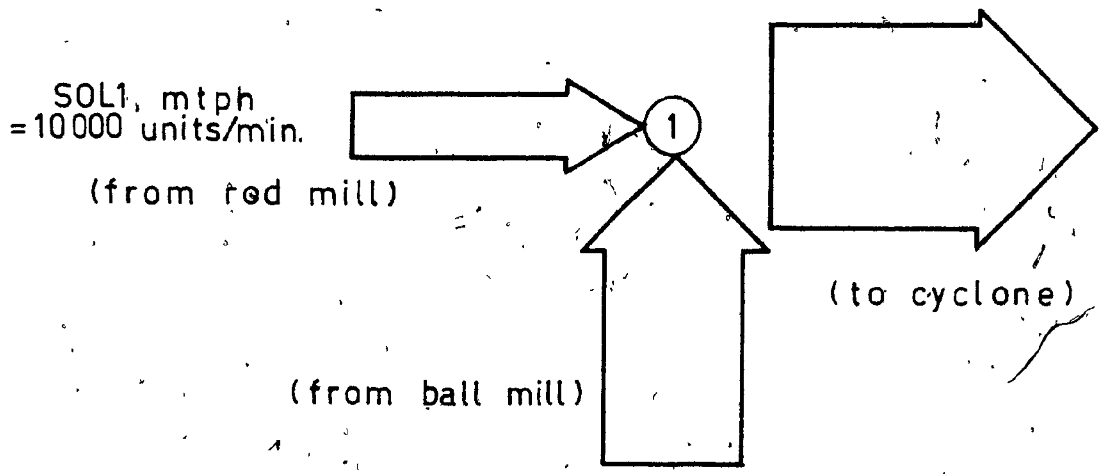
Two kinds of input data to the program are provided: input data associated with the fresh feed to the closed circuit and input data associated with the mathematical models of grinding and classification.

4.1.1 Ball Mill Volumetric Holdup Calculations

These calculations are made from geometric considerations of mill size and grinding media volume. For details, see Appendix III, Section III.4.

4.1.2 Mineral Units

An arbitrary mineral unit was selected and consistently used in the program. The selection was as follows: firstly, transformation of the dry solids, fresh tonnage input to a fixed amount of 10,000 units/min. Secondly, the above units are split into the mineral contribution of all the components composing the ore. Schematically:



The input mineral units are calculated using the product of size and chemical assays and stoichiometric factors.

Through the iterative process, the program handles mineral units/min. When it is necessary to compute the residence time (in minutes) and pulp dilutions, two transforming factors are utilized. The factors are calculated as follows:

$$SOL1 \cdot TON/60 = 10{,}000\ UNIT \tag{4.1}$$

Thus,

$$TON = 600{,}000\ UNIT/SOL1 \tag{4.1a}$$

and the reciprocal,

$$UNIT = 1/TON \tag{4.1b}$$

where: SOL1 = fresh feed input in tonnes/hr

TON = factor to convert tonnes to mineral units

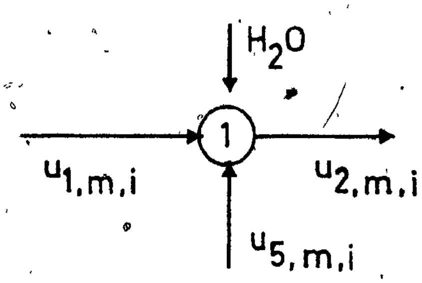
UNIT = factor to convert units to tonnes

4.1.3 Mass Flow Balances

Figure 1.1 shows the actual circuit. Five streams numbered from 1 to 5 completely define the closed circuit. From the solids and water mass balances around the three nodes (sump, cyclone and ball mill), rate ratios are calculated. These mass balances make use of simple additions (or subtractions) and of the mathematical models. The following is the logic sequence used by the program to calculate the mass flow rate balances:

Node 1 (Sump)

Calculation of Mineral Units ($u_{1,m,i}$) in units/min.



$$u_{1,m,i} = size_{1,i} \cdot chem_{1,m,i} \cdot f_m$$

where: $size_{1,i}$ - is the size assay of ore in stream 1, pct.

$chem_{1,m,i}$ - is the size element assay of minerals m in stream 1, pct.

f_m - is the stoichiometric factor of minerals m to convert from element assay to mineral assay.

First Iteration (m = 1)

$$u_{1,m,i} = u_{2,m,i}$$

$$WAT1 + WAT5 = WAT2$$

Second Iteration (m = 2)

$$u_{1,m,i} + u_{5,m,i} = u_{2,m,i}$$

$$WAT1 + WAT5 = WAT2$$

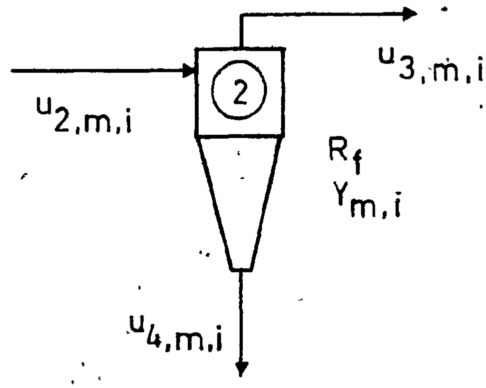
.
.
.
etc.

where: $u_{2,m,i}$ and $u_{5,m,i}$ = mineral units/min of streams 2 and 5, respectively.

WAT1, WAT2 and WAT5 are water flow rates of streams 1, 2 and 5, respectively. Units: m^3/min.

NOTE: For computing purposes, WAT5 includes the make-up water added to the sump, and the diluting water of stream 5.

Node 2 (Cyclone)



$$u_{4,m,i} = u_{2,m,i} \cdot Y_{m,i}$$

$$u_{3,m,i} = u_{2,m,i} - u_{4,m,i}$$

$$WAT4 = R_f \cdot WAT2$$

$$WAT3 = WAT2 - WAT4$$

where: $u_{3,m,i}$ and $u_{4,m,i}$ - are mineral units/min in streams 3 and 4, respectively.

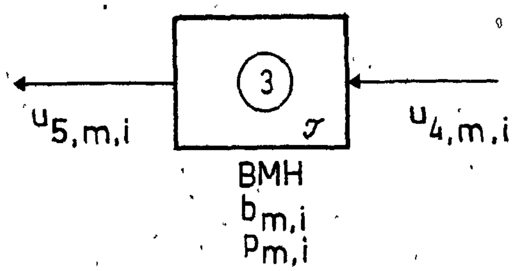
$Y_{m,i}$ - is the cyclone selectivity index matrix

R_f - is the splitting ratio of water from the feed to the cyclone underflow.

WAT3 and WAT4 - are water flow rates in streams 3 and 4, respectively. Units: m^3/min.

Node 3 (Ball Mill)

First Iteration (m = 1)



Calculation of Cumulative Mineral-by-Mineral Units in Stream 4

$$Cu_{4,m,i} = \Sigma u_{4,m,i}$$

Calculation of Total Volume Flow Rate (m^3/min)

$$V_T = V_{SOL} + V_{H_2O}$$

$$V_{SOL} \quad \sum_{m=1}^{4} (Cu_{4,m,n}/\rho_m \;.\; TON)$$

where: V_T - total volume flow rate in m^3/min

V_{SOL} - volume flow rate of all minerals in m^3/min

V_{H_2O} - WAT4 in m^3/min

$Cu_{4,m,n}$ - total mineral units of mineral m in stream 4 in units/min

ρ_m - specific gravity of mineral m in tonnes/m^3

TON - factor to convert tonnes to mineral units

n - mesh number

Calculation of Ball Mill Mean Residence Time, τ in min

$$\tau = BMH/V_T$$

where: BMH - ball mill volume holdup in m^3

Calculation of Mineral-by-Mineral Size Reduction

$$Cu_{5,m,i} = Cu_{4,m,i} \exp\{- Fg_m \;.\; b_{m,i}\; \tau^{p_{m,i}}\}$$

where: $Cu_{5,m,i}$ - is cumulative mineral units on screen i in units/hr

Fg_m - is plant-data fitted parameter

$b_{m,i}$ - is specific rate of breakage of mineral m of all sizes larger than i in $min^{-p_{m,i}}$

$p_{m,i}$ - is the order of breakage, dimensionless

Calculation of Mineral Units $u_{5,m,i}$ in units/hr

$$u_{5,m,i} = Cu_{5,m,i+1} - Cu_{5,m,i}$$

Calculation of Δ, the Convergence Criterion (units/min)

$$\Delta = (M1T - M3T)$$

where: M1T - is 10,000 units/min

M3T - is the total mineral units in the COF in units/min after any number of iterations

4.1.4 Calculation of Miscellaneous Printout

Once the convergence criterion (0.1% by weight) is reached, several calculations are performed. These are:

a) overall circulating load
b) mineral-by-mineral circulating loads
c) pulp dilution in all streams
d) overall CUM. WT. PCT. finer in all streams
e) mineral-by-mineral size frequency distributions (size-by-size and in CUM. finer form)
f) mineral-by-mineral instantaneous rates of breakage at steady state conditions

In addition, the printout includes the number of iterations to reach the steady state condition, the mean residence time, and the computed steady state overall specific gravity of ball mill feed material.

4.1.5 Criterion to Select the Grinding Factor Fg_m

As already mentioned in the Theory section, a grinding factor is introduced in the batch grinding model to account for residence time distributions of the minerals and possibly mill size scaling considerations. Thus, this factor is a lumped plant fitting parameter. The criterion was to choose Fg_m values which reproduced the mineral circulating load determined from the adjusted plant data.

4.2 Simulation of Actual Circuit - Combined Classification Model (Mineral-by-Mineral)

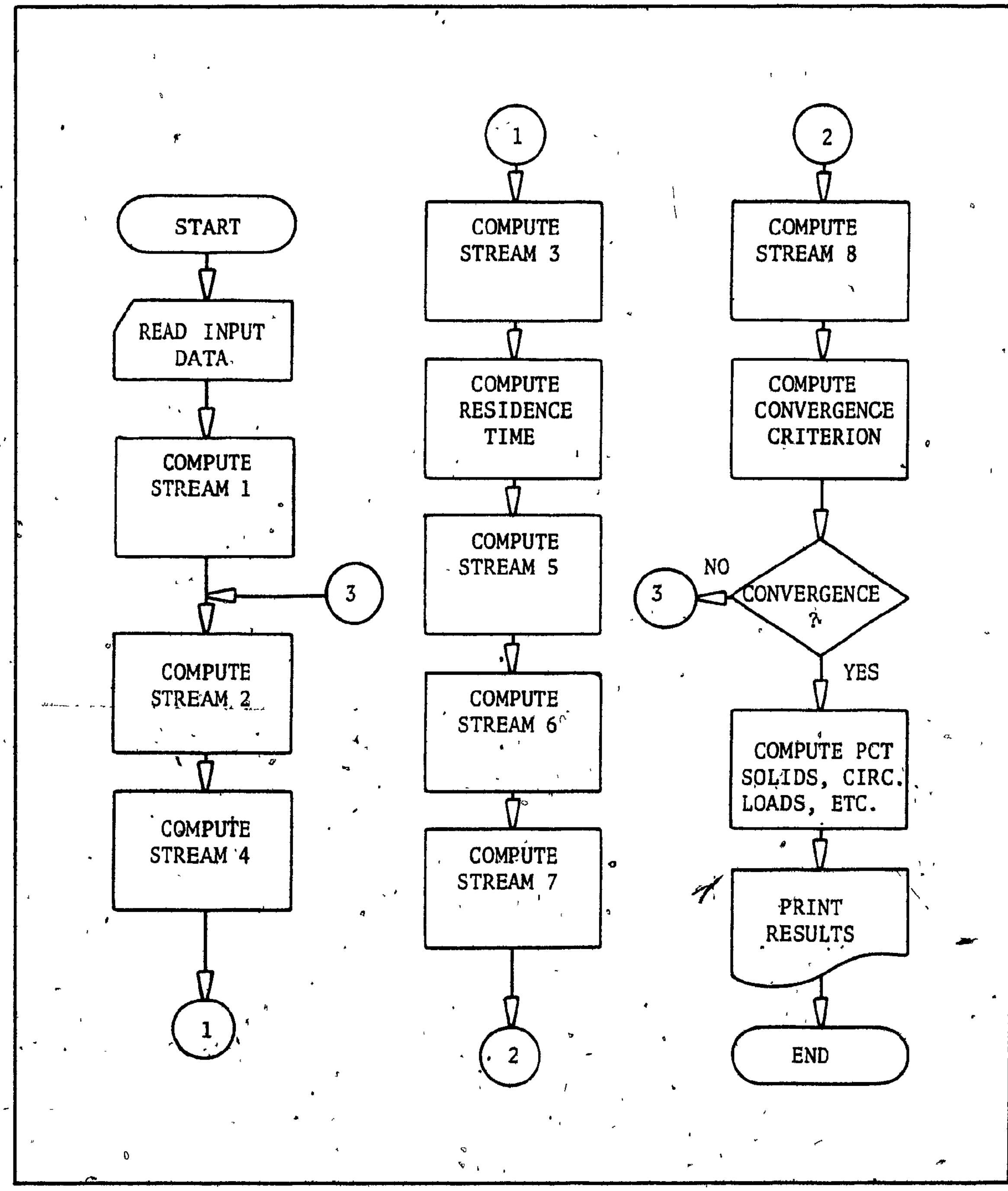
A computer program, using the same methodology of the previous section, was written incorporating the combined Lynch and general classification models described in Sections 2.2.4.1 and 2. The program, iteratively, computes the water splitting ratio R_f and $d_{50(C)}$ for calcite/dolomite given by Equations (2.2.9) and (2.2.10), respectively. Equation (2.2.7) is used to calculate $d_{50(C)}$ for PbS, ZnS and FeS_2. The short-circuiting of fines to the underflow of the individual minerals is assumed equal to R_f. The sharpness of classification, n_m, of Equation (2.2.5) was assumed constant (the average n_m of all minerals individually). Appendix V, Section V.2, contains the program.

4.3 Prediction of Proposed Circuit (Mineral-by-Mineral)

Figure 4.2 shows the flow chart diagram of the computer program used for predicting the performance of the proposed circuit shown in Figure 1.2. Except for the Pb flotation stage, the program is the same as for the one described in 4.3 above.

FIGURE 4.2

Simplified flow chart diagram of computer program to simulate the proposed closed grinding circuit.


START
READ INPUT DATA
COMPUTE STREAM 1
3
COMPUTE STREAM 2
COMPUTE STREAM 4
1
1
COMPUTE STREAM 3
COMPUTE RESIDENCE TIME
COMPUTE STREAM 5
COMPUTE STREAM 6
COMPUTE STREAM 7
2
2
COMPUTE STREAM 8
COMPUTE CONVERGENCE CRITERION
CONVERGENCE ?
NO
3
YES
COMPUTE PCT SOLIDS, CIRC. LOADS, ETC.
PRINT RESULTS
END

To provide for a convenient pulp dilution in the flotation unit, the model contemplates all water is added at the ball mill discharge. The water mass balance across the cell is completed by assuming a dry concentrate.

The convergence criterion is as for the previous program but the product of the closed circuit now contains two separate streams (Figure 1.2): cyclone overflow (stream 3) and flotation concentrate (stream 7). Only for computing of Δ, the convergence criterion, streams 3 and 6 are added together to form stream 8. (In practice, the stream of PbS concentrate should be sent for cleaning and the cyclone overflow stream be sent to the conventional PbS rougher stage.) Appendix V, Section V.3, contains the program written for simulating the proposed circuit.

4.4 Comparison of Plug Flow and Tanks-in-Series Models (Overall)

Two simulations were made: one using the plug flow grinding model - Equation (2.1.8) - and the other, using the three 'tanks' in series model tank A, tank B and tank C. Tank A was a plug flow mill with 0.2 τ mean residence time; tanks B and C were fully-mixed mills - Equation (2.1.12) - with 0.4 τ mean residence time each. τ was calculated by means of Equation (2.1.13).

Two computer programs were written to simulate the grind circuit, one for each grind model. These, iteratively compute the overall flow rates across the entire circuit until a finite difference between circuit feed (RMD) and circuit product (cyclone overflow) is achieved. This is the convergence criterion, set at 0.1% mass flow rate by weight.

Both programs were written using solids and water mass balances around the circuit. The grinding and classification models both utilized overall parameters (p-order grind kinetics and the selectivity index matrix Y_i). The programs calculate the overall size reduction of the grind unit and the closed circuit. For each stream of the circuit, the results are given as weight percent retained and cumulative weight percent finer. The programs are shown in Appendix V, Sections V.4 and V.5.

CHAPTER V

RESULTS

5.1 Laboratory

5.1.1 Silica

Tables 5.1 to 5.8 summarize the results of experiments 1 to 8, respectively. The tables report the size assays of feed and grindi[ng] products. Also shown are the first and p-order kinetics k_i, p_i and b_i obtained by regression. The first order plots of experiments 1 to 8 are shown on Figures 5.1 to 5.6. Note that experiments 2 and 3 are plotted on the same graph (Figure 5.2), whilst experiments 7 and 8 are both plotted in Figure 5.6. The coordinate system utilized is semi log where the lines shown were determined with the least square techn[ique] and the slopes represent the first order rate-of-breakage, k_i. The equation used was Equation (2.1.6). Also, the experimental results of experiments 1 to 8 are shown on Figures 5.7 to 5.12. These are the p-order plots where the Rosin-Rammler chart was used as coordinate syste[m]. The X-axis is log {TIME} and the Y-axis is log log {1/(1 - Y)} where [Y] is cumulative weight fraction finer. The equations used in the regres[s]ion analysis were Equations (2.1.7a) and (2.1.8a).

The results indicate that either first or p-order is an adequate fit. In more detail, the similarity between experiments 2 and 3 indicate that the one-sample-at-a-time and recycling methods yi[eld the] same result. Also, experiments 7 and 8 (see Figure 5.12) indicate th[e] data is very reproducible. The effect of void filling is illustrated

TABLE 5.1 Experiment No. 1.
Particle Size Distributions (PCT) and Grinding Kinetics.
(First-Order and p-Order).

Mesh No.	Grind Time, min							Grind Kinetics		
	Feed	2	4	6	8	10	12	k_i	p_i	b_i
28	23.57	8.84	3.23	1.18	0.39	0.15	0.06	0.5040	1.0154	0.4867
48	32.30	31.44	25.36	18.51	12.68	8.31	5.26	0.2031	1.1016	0.1487
100	17.25	22.68	25.80	26.57	26.04	24.26	22.10	0.0835	1.0529	0.0705
200	11.60	15.93	19.63	22.22	24.39	26.05	27.46	0.0369	1.0221	0.0342
400	6.79	9.25	11.52	14.07	16.78	18.29	20.59	0.0159	0.9318	0.0192
-400	8.49	11.86	14.46	17.45	19.72	22.94	24.53			

TABLE 5.2 Experiment No. 2.
Particle Size Distributions (PCT) and Grinding Kinetics.
(First-Order and p-Order).

Mesh No.	Grind Time, min							Grind Kinetics		
	Feed	2	4	6	8	10	12	k_i	p_i	b_i
28	12.50	4.61	1.70	0.63	0.23	0.09	0.04	0.4995	1.0419	0.4444
48	33.63	27.56	20.53	14.51	9.70	5.89	3.90	0.2139	1.0994	0.1865
100	22.93	25.57	27.33	26.70	25.28	25.86	20.41	0.0840	0.9882	0.0821
200	13.17	17.12	19.86	22.28	24.57	23.99	26.55	0.0385	0.9441	0.0372
400	7.57	9.49	11.38	13.62	15.31	15.89	18.22	0.0204	0.8470	0.0167
-400	10.20	15.20	18.81	22.08	24.84	28.24	30.89			

TABLE 5.3 Experiment No. 3.
Particle Size Distributions (PCT) and Grinding Kinetics.
(First-Order and p-Order).

Mesh No.	Grind Time, min							Grind Kinetics		
	Feed	2	4	6	8	10	12	k_i	p_i	b_i
28	12.50	5.63	2.23	0.77	0.32	0.10	0.03	0.5195	1.2221	0.3657
48	33.63	27.33	20.63	14.67	9.94	6.31	3.84	4.2133	1.1095	0.1528
100	22.93	26.14	27.31	26.96	25.52	23.19	20.39	0.0886	1.0579	0.0741
200	13.17	15.99	19.32	22.00	23.92	25.55	26.69	0.0387	0.9261	0.0471
400	7.57	9.79	11.81	13.66	15.32	16.94	18.38	0.0202	0.8501	0.0309
-400	10.20	15.12	18.70	21.94	24.98	27.91	30.67			

TABLE 5.4 Experiment No. 4.
Particle Size Distributions (PCT) and Grinding Kinetics.
(First-Order and p-Order).

Mesh No.	Grind Time, min							Grind Kinetics		
	Feed	1	3	4	6	8	10	k_i	p_i	b_i
28	12.50	8.86	4.15	2.96	1.37	0.57	0.26	0.3945	1.0492	0.3519
48	33.63	30.78	25.95	23.12	18.02	13.61	9.82	0.1576	1.0132	0.1396
100	22.93	24.94	27.20	22.77	28.22	27.70	26.54	0.0647	0.9832	0.0635
200	13.17	15.20	18.38	19.74	22.06	23.91	25.68	0.0280	0.9677	0.0291
-200	17.77	20.26	24.32	26.41	30.33	34.21	37.70			

TABLE 5.5 Experiment No. 5.
Particle Size Distributions (PCT) and Grinding Kinetics.
(First-Order and p-Order).

Mesh No.	Grind Time, min									Grind Kinetics		
	Feed	0.5	1	2	4	6	8	10	12	k_i	p_i	b_i
28	100.00	85.84	74.18	56.20	31.63	16.72	8.65	4.47	2.28	0.3148	1.0108	0.2976
48	0.00	10.47	17.50	27.22	36.65	37.27	33.42	27.72	22.17	0.1182	1.1284	0.0834
100	0.00	2.05	4.37	8.55	15.60	21.04	24.95	27.43	28.47	0.0549	1.1333	0.0379
200	0.00	0.94	2.25	4.38	8.68	12.72	16.27	19.40	21.85	0.0245	1.1606	0.0164
-200	0.00	0.70	1.70	3.65	8.04	12.25	16.71	20.90	25.32			

TABLE 5.6 Experiment No. 6.
Particle Size Distributions (PCT) and Grinding Kinetics.
(First-Order and p-Order).

Mesh No.	Grind Time, min							Grind Kinetics		
	Feed	2	4	6	8	10	12	k_i	p_i	b_i
28	100.00	50.96	25.61	12.05	5.14	2.25	0.86	0.4079	1.0893	0.3086
48	0.00	28.94	36.69	34.51	28.62	20.89	15.20	0.1616	1.1746	0.0960
100	0.00	10.03	17.74	23.60	27.11	28.68	28.13	0.0714	1.1407	0.0469
200	0.00	5.23	10.05	14.75	18.66	22.22	24.56	0.0325	1.1274	0.0222
400	0.00	2.38	4.81	7.31	9.75	12.37	14.41	0.0159	1.1118	0.0113
-400	0.00	2.46	5.10	7.78	10.72	13.59	16.84			

TABLE 5.7 Experiment No. 7.
Particle Size Distributions (PCT) and Grinding Kinetics.
(First-Order and p-Order).

Mesh No.	Grind Time, min							Grind Kinetics		
	Feed	2	4	6	8	10	12	k_i	p_i	b_i
8	3.60	1.64	0.53	0.25	0.11	0.02	0.00	0.5193	1.0725	0.3923
10	12.80	4.76	1.89	0.78	0.26	0.08	0.05	0.4978	1.0249	0.4583
14	17.80	9.69	4.98	2.19	0.89	0.28	0.10	0.4746	1.1083	0.3380
20	15.90	12.79	8.10	4.30	2.25	1.14	0.41	0.3920	1.1663	0.2389
28	12.70	14.33	12.11	8.37	5.66	3.23	1.79	0.2912	1.2124	0.1575
35	9.80	12.90	13.76	12.40	9.94	7.70	5.06	0.2017	1.2149	0.1079
48	7.00	11.41	14.62	15.67	15.23	14.14	12.19	0.1238	1.1981	0.0697
65	5.30	7.41	9.97	11.67	12.22	12.58	12.41	0.0856	1.1559	0.0539
100	4.00	6.47	9.46	11.44	13.25	14.45	15.18	0.0552	1.1175	0.0383
150	2.90	4.44	5.22	8.52	10.08	11.52	12.66	0.0360	1.0326	0.0317
200	2.00	3.43	4.59	6.40	7.72	8.93	10.34	0.0240	0.9816	0.0245
270	1.60	2.81	4.10	5.27	6.43	7.62	8.00	0.0160	0.9425	0.0177
400	1.30	1.58	2.25	2.79	3.59	3.98	4.68	0.0120	0.8617	0.0167
-400	3.30	6.34	8.42	9.95	12.37	14.33	17.13			

TABLE 5.8 Experiment No. 8.
(Repeat of Experiment No. 7).
Particle Size Distributions (PCT) and Grinding Kinetics.
(First-Order and p-Order).

Mesh No.	Grind Time, min							Grind Kinetics		
	Feed	2	4	6	8	10	12	k_i	p_i	b_i
8	3.60	1.64	0.57	0.20	0.05	0.03	0.00	0.5218	1.1529	0.3632
10	12.80	5.03	1.74	0.61	0.35	0.08	0.04	0.5060	1.0478	0.4441
14	17.80	9.90	4.70	2.09	0.80	0.33	0.15	0.4504	1.1019	0.3405
20	15.90	12.80	8.10	4.46	2.22	1.14	0.44	0.3821	1.1681	0.2371
28	12.70	13.75	11.80	8.55	5.57	3.24	1.86	0.2855	1.1983	0.1621
35	9.80	12.49	13.33	12.16	9.83	7.59	5.37	0.1959	1.1827	0.1158
48	7.00	11.27	14.43	15.63	15.32	14.14	12.40	0.1198	1.1516	0.0772
65	5.30	7.65	9.77	11.29	12.21	12.51	12.40	0.0828	1.1140	0.0595
100	4.00	6.73	9.25	11.28	12.95	13.98	14.75	0.0542	1.0890	0.0419
150	2.90	4.58	6.66	8.45	9.99	11.14	11.99	0.0370	1.0472	0.0319
200	2.00	3.44	4.99	6.46	7.81	8.96	9.87	0.0255	1.0160	0.0238
270	1.60	2.75	3.99	5.19	6.41	7.48	8.48	0.0169	0.9738	0.0177
400	1.30	1.55	2.21	2.95	3.48	4.01	4.62	0.0128	0.8912	0.0168
-400	3.30	6.42	8.46	10.68	13.01	15.37	17.63			

FIGURE 5.1

Experiment No.1. Results. First-order plots.

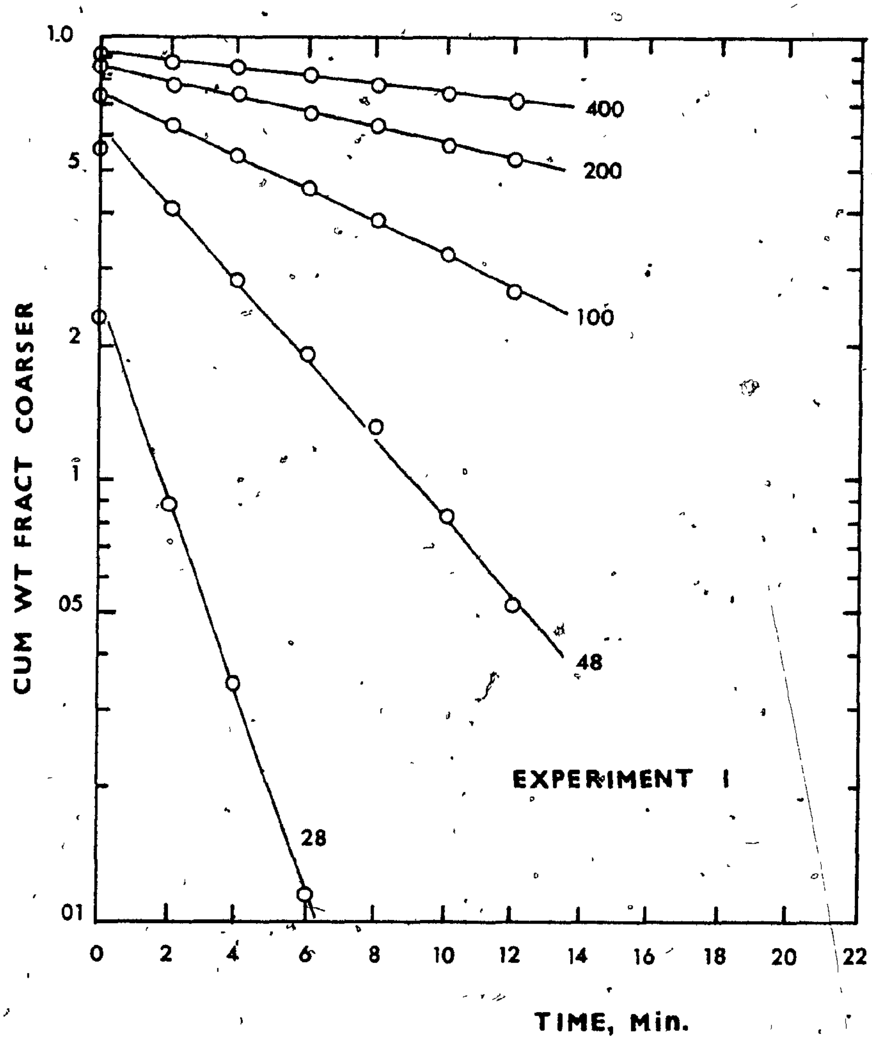
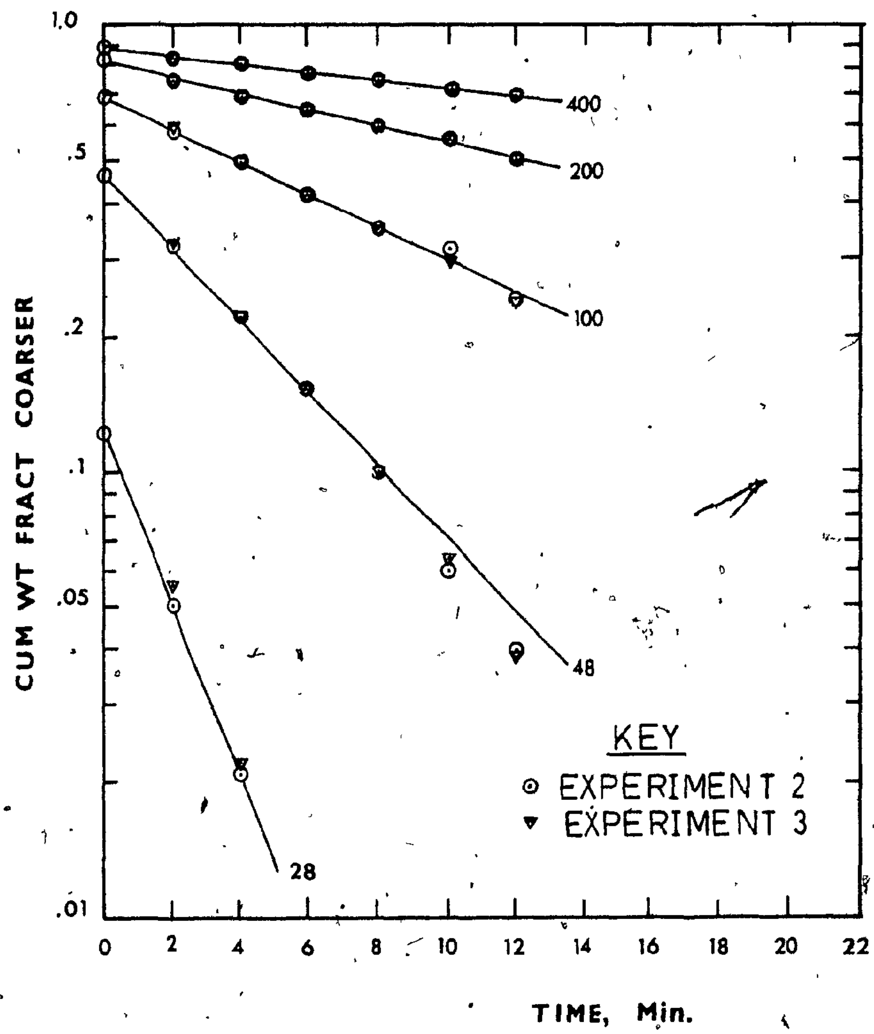

1.0
5
2
1
05
01
CUM WT FRACT COARSER
400
200
100
48
28
EXPERIMENT I
0
2
4
6
8
10
12
14
16
18
20
22
TIME, Min.

FIGURE 5.2

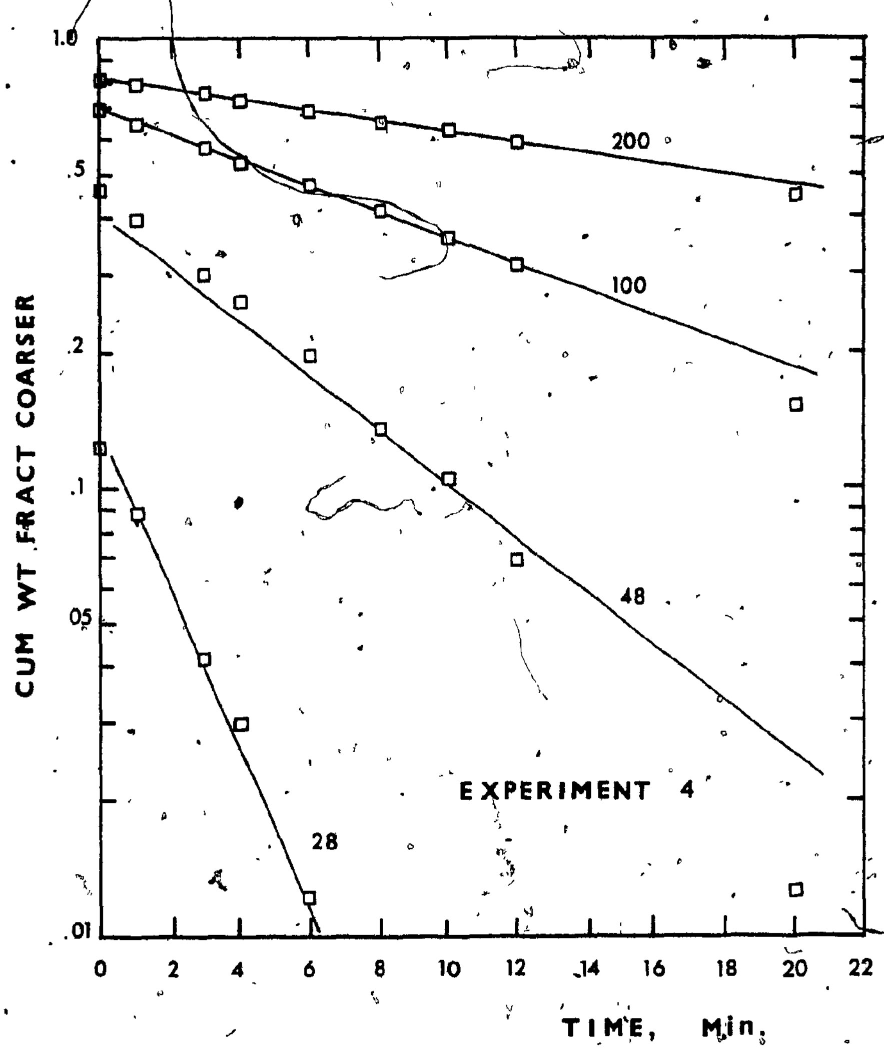
Experiments No.2 and 3. Results. First-order plots.



1.0
.5
.2
.1
.05
.01
CUM WT FRACT COARSER
400
200
100
48
28
KEY
EXPERIMENT 2
EXPERIMENT 3
0
2
4
6
8
10
12
14
16
18
20
22
TIME, Min.

FIGURE 5.3

Experiment No.4. Results. First-order plots.



CUM WT FRACT COARSER
1.0
.5
.2
.1
.05
.01
200
100
48
28
EXPERIMENT 4
0
2
4
6
8
10
12
14
16
18
20
22
TIME, Min.

FIGURE 5.4

Experiment No.5. Results. First-order plots.

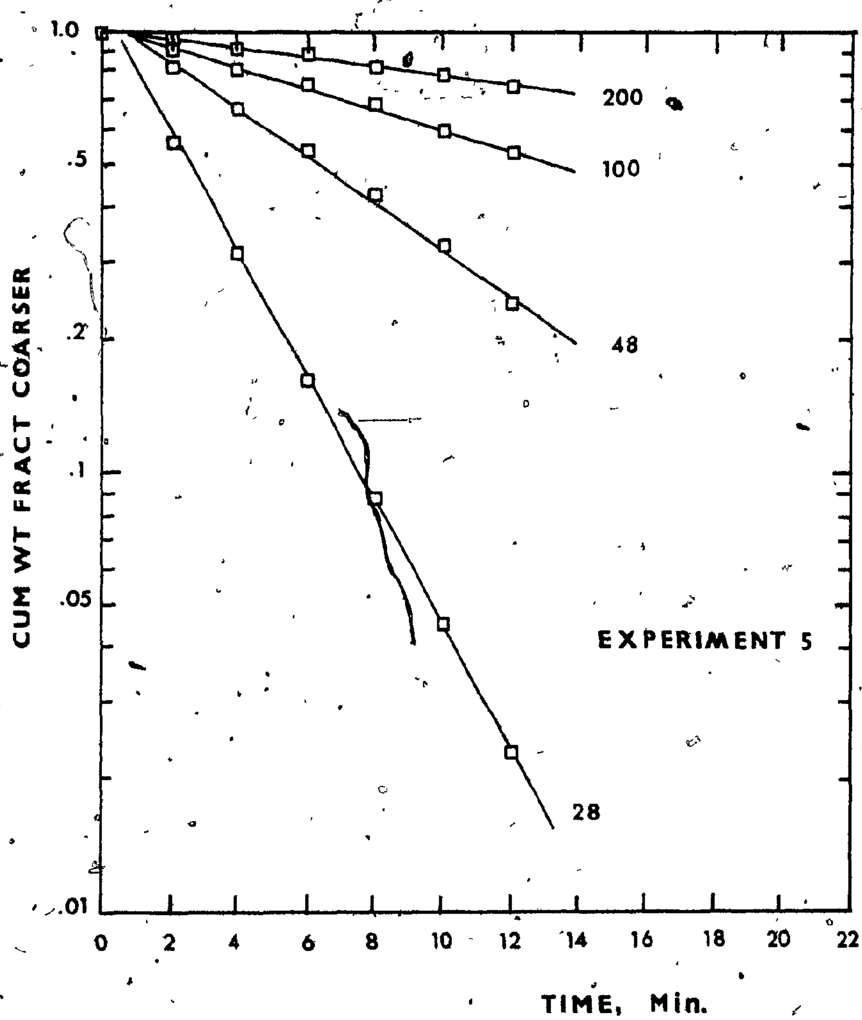
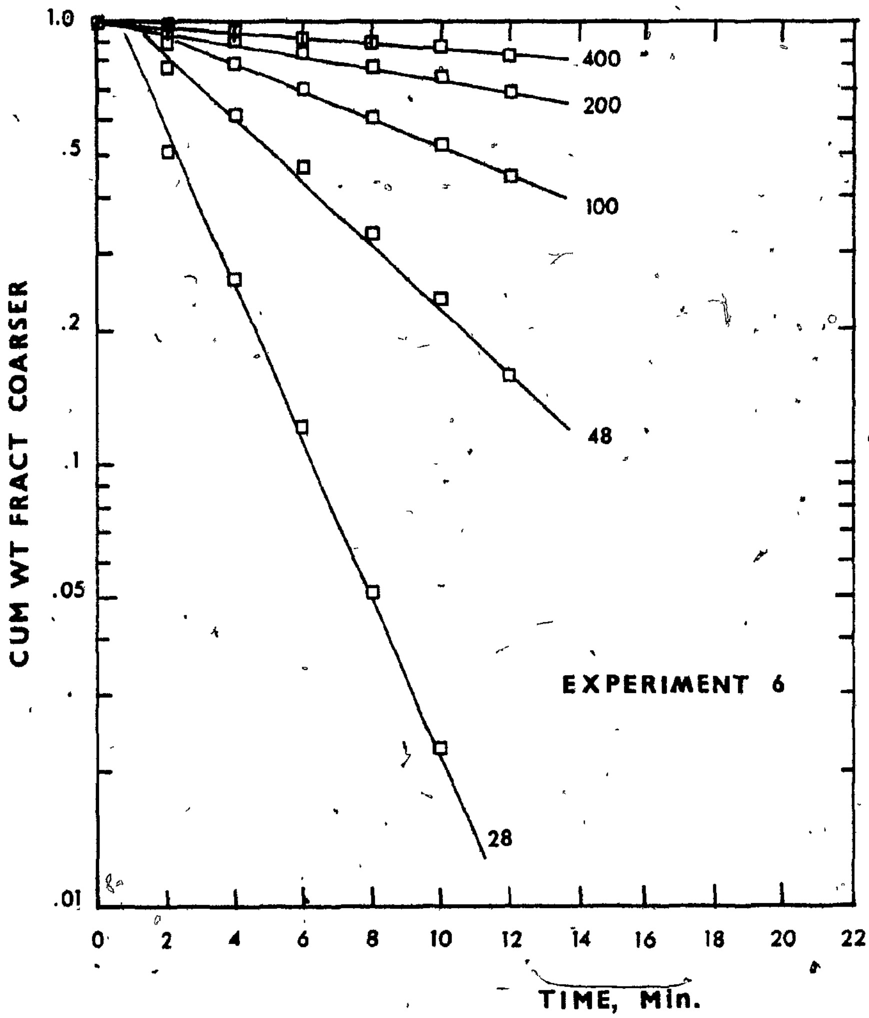

1.0
.5
.2
.1
.05
.01
CUM WT FRACT COARSER
200
100
48
28
EXPERIMENT 5
0
2
4
6
8
10
12
14
16
18
20
22
TIME, Min.

FIGURE 5.5

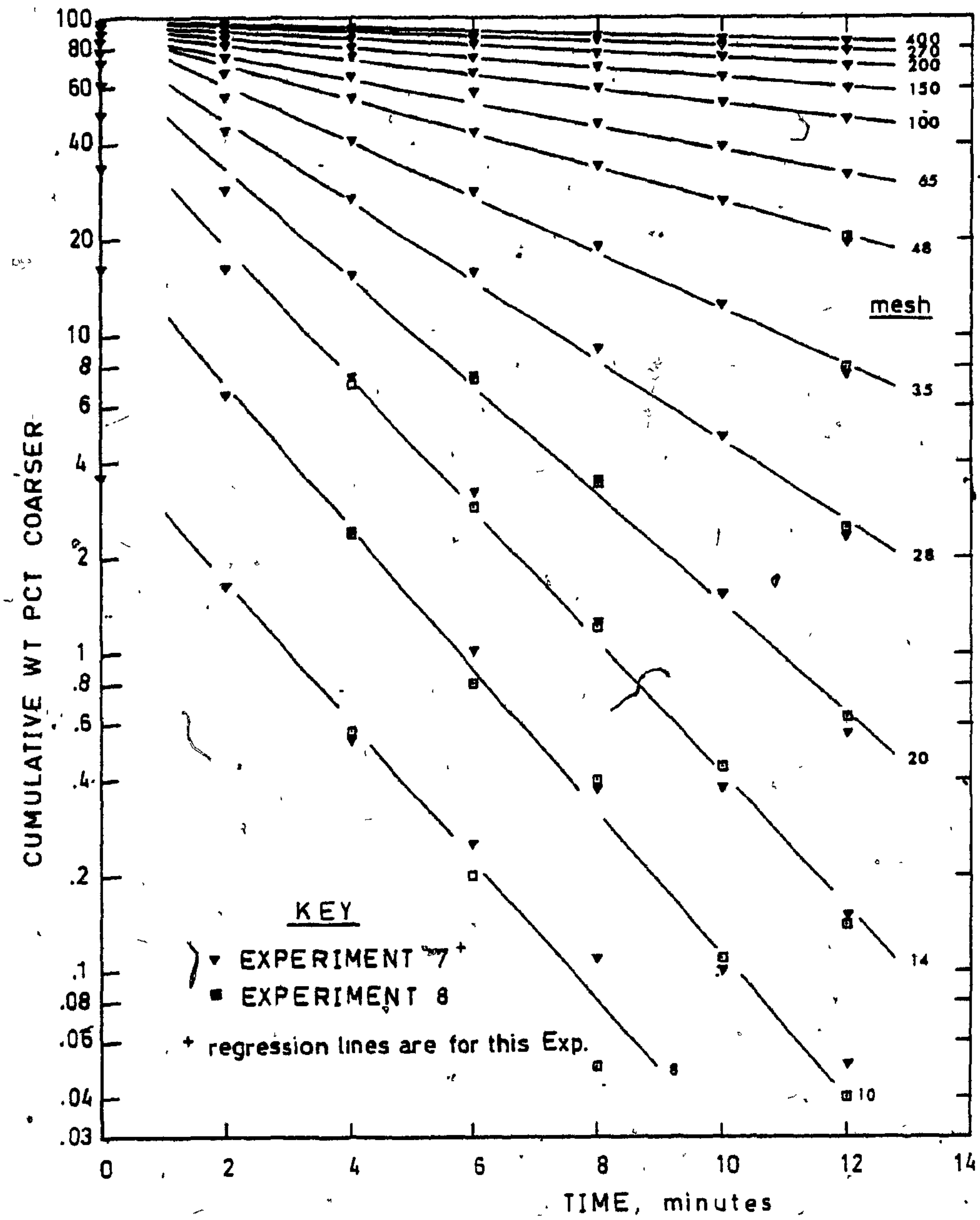
Experiment No.6. Results. First-order plots.



1.0
.5
.2
.1
.05
.01
CUM WT FRACT COARSER
400
200
100
48
28
EXPERIMENT 6
0
2
4
6
8
10
12
14
16
18
20
22
TIME, Min.

FIGURE 5.6

Experiments No.6 and 7. Results. First-order plots.



CUMULATIVE WT PCT COARSER
TIME, minutes
mesh
400
270
200
150
100
65
48
35
28
20
14
10
8
KEY
EXPERIMENT 7+
EXPERIMENT 8
+ regression lines are for this Exp.

FIGURE 5.7

Experiment No.1. Results. p-order plots.

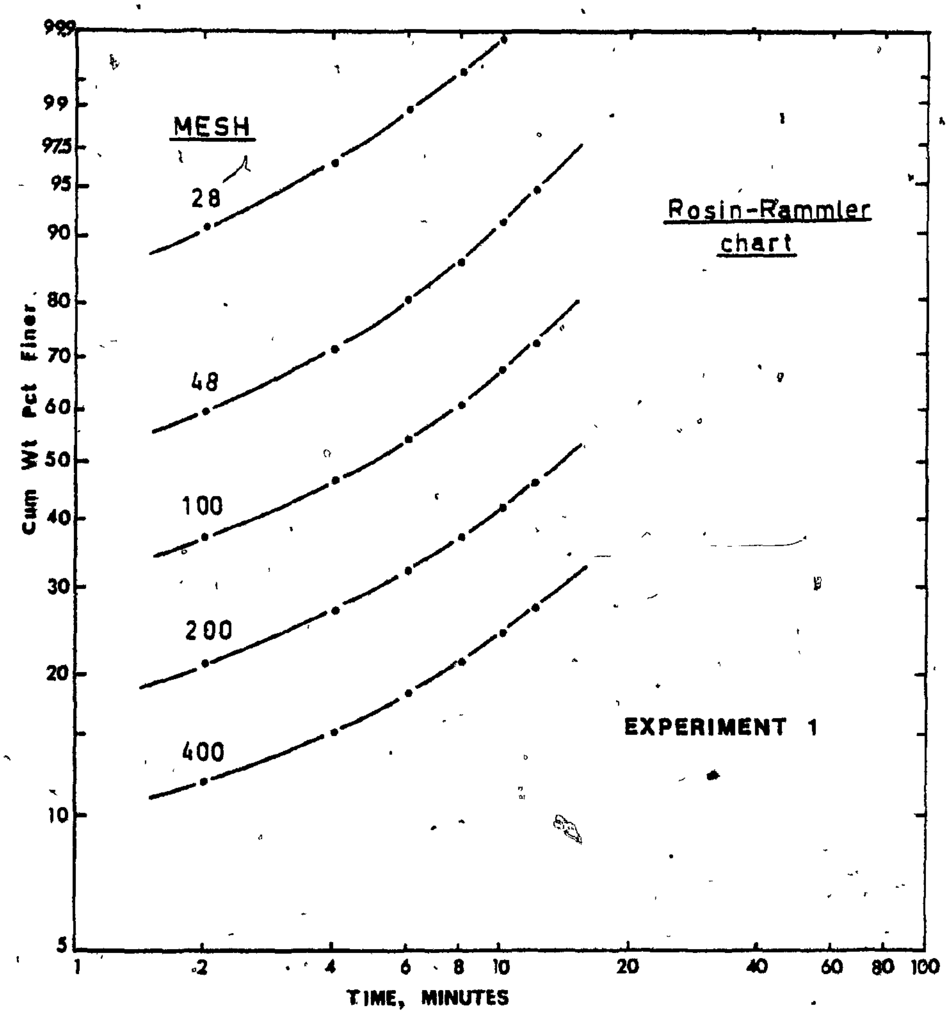
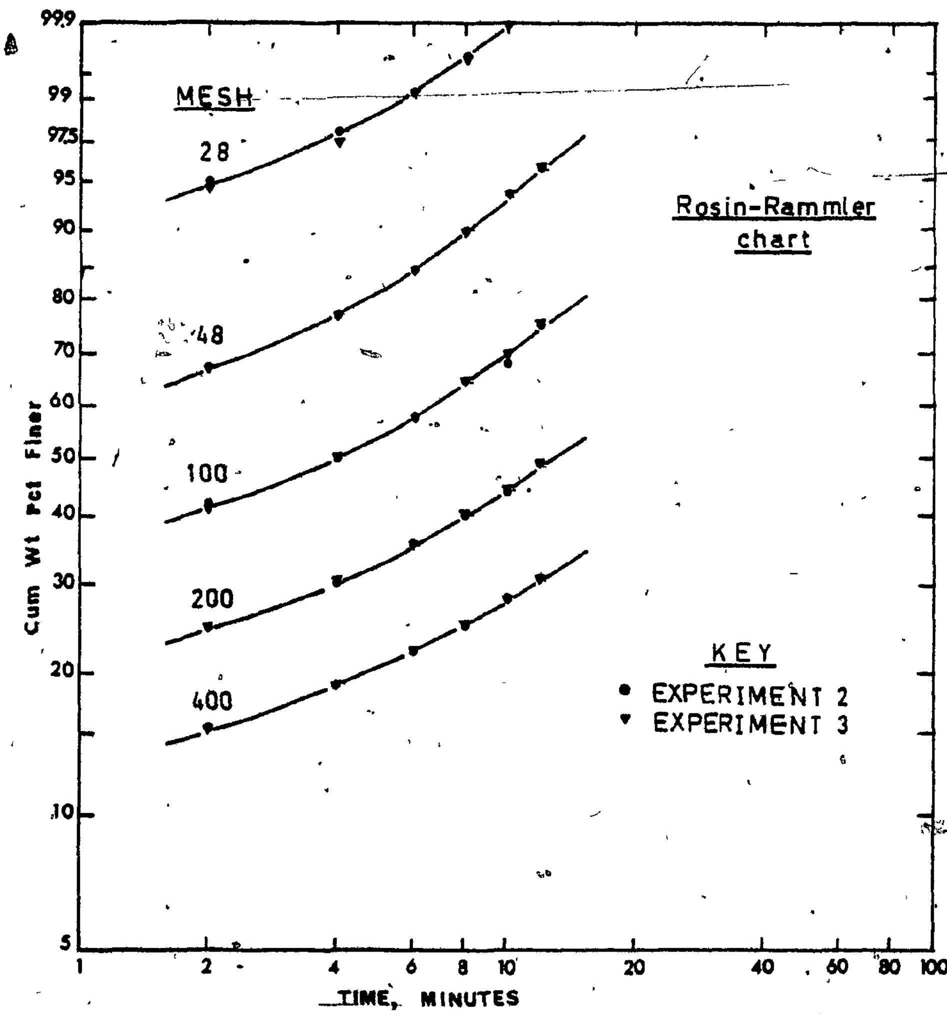

MESH
28
48
100
200
400
Rosin-Rammler chart
EXPERIMENT 1
Cum Wt Pct Finer
TIME, MINUTES

FIGURE 5.8

Experiments No.2 and 3. Results. p-order plots.



MESH
28
48
100
200
400
Rosin-Rammler chart
KEY
EXPERIMENT 2
EXPERIMENT 3
Cum Wt Pct Finer
TIME, MINUTES
99.9
99
97.5
95
90
80
70
60
50
40
30
20
10
5
1
2
4
6
8
10
20
40
60
80
100

FIGURE 5.9

Experiment No. 4. Results. p-order plots.

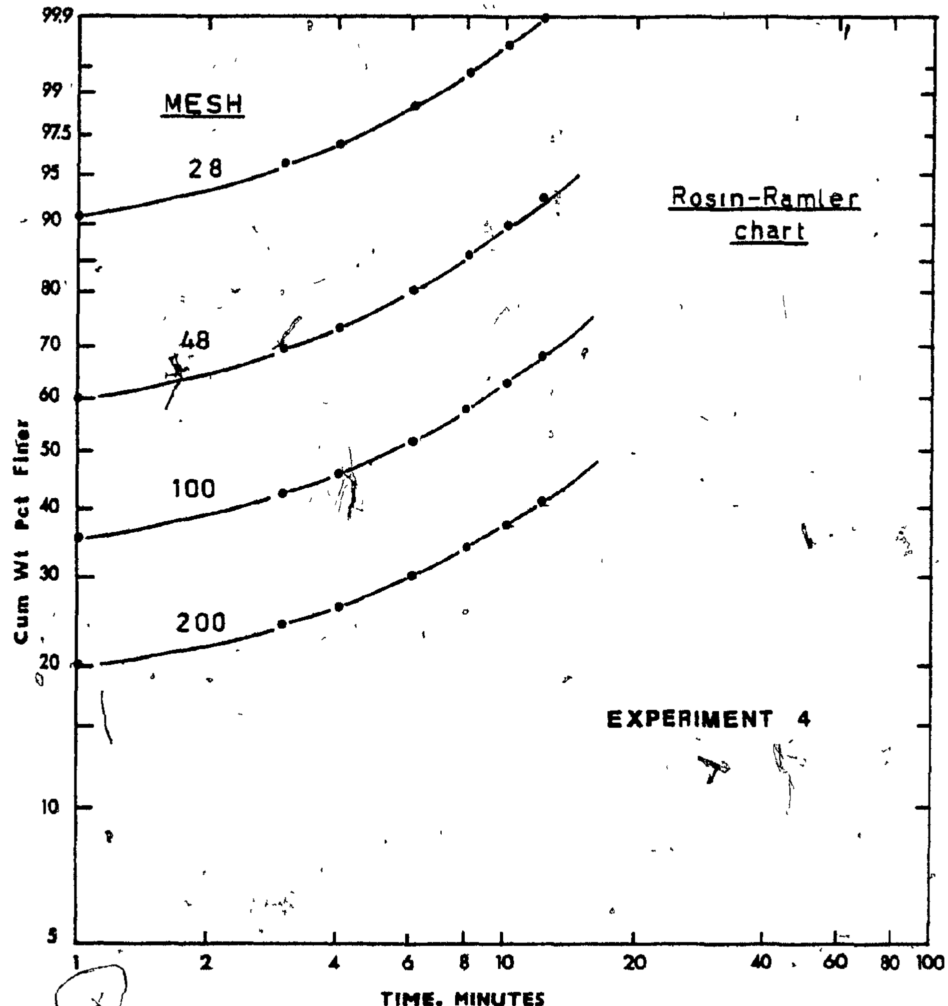
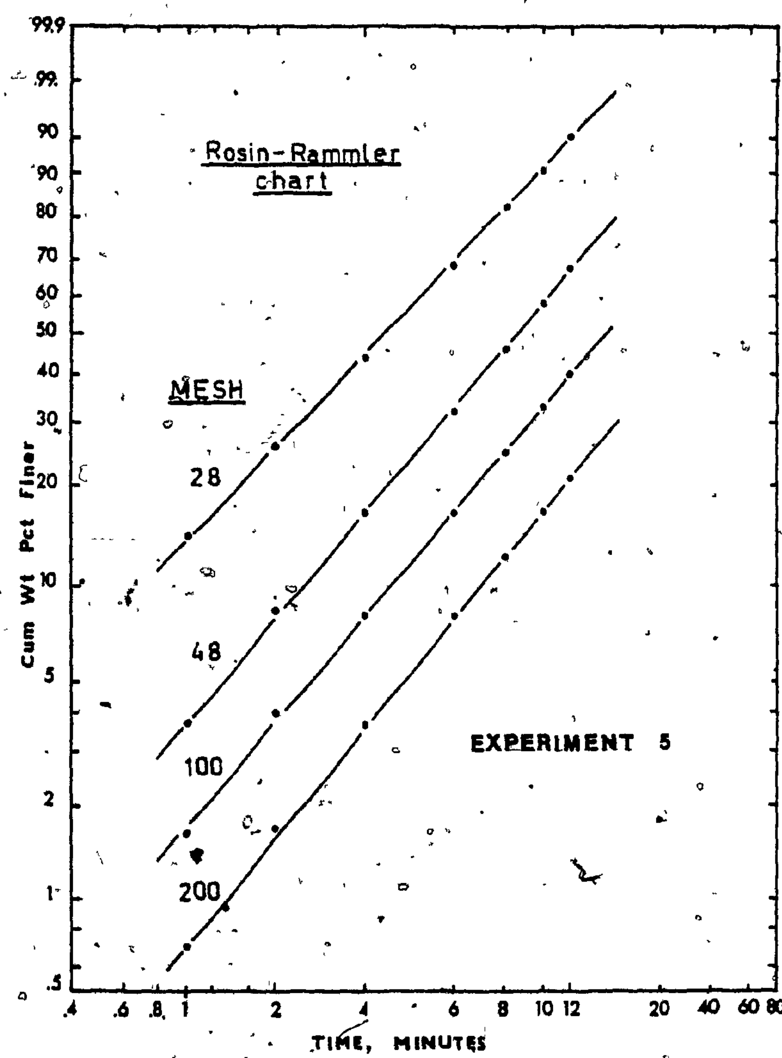

MESH
28
48
100
200
Rosin-Ramler chart
EXPERIMENT 4
Cum Wt Pct Finer
TIME, MINUTES
99.9
99
97.5
95
90
80
70
60
50
40
30
20
10
5
1
2
4
6
8
10
20
40
60
80
100

FIGURE 5.10

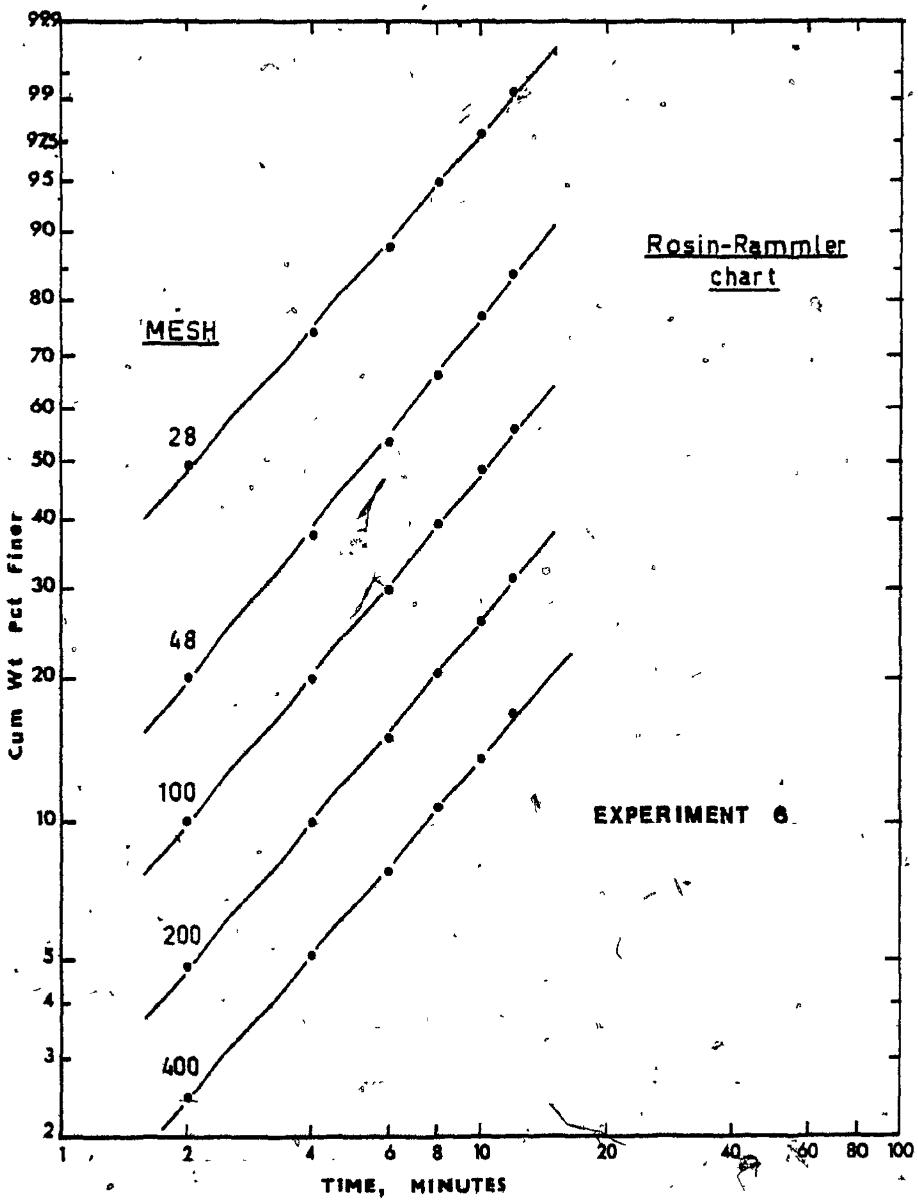
Experiment No.5. Results. p-order plots.



Rosin-Rammler chart
MESH
28
48
100
200
EXPERIMENT 5
Cum Wt Pct Finer
TIME, MINUTES

FIGURE 5.11

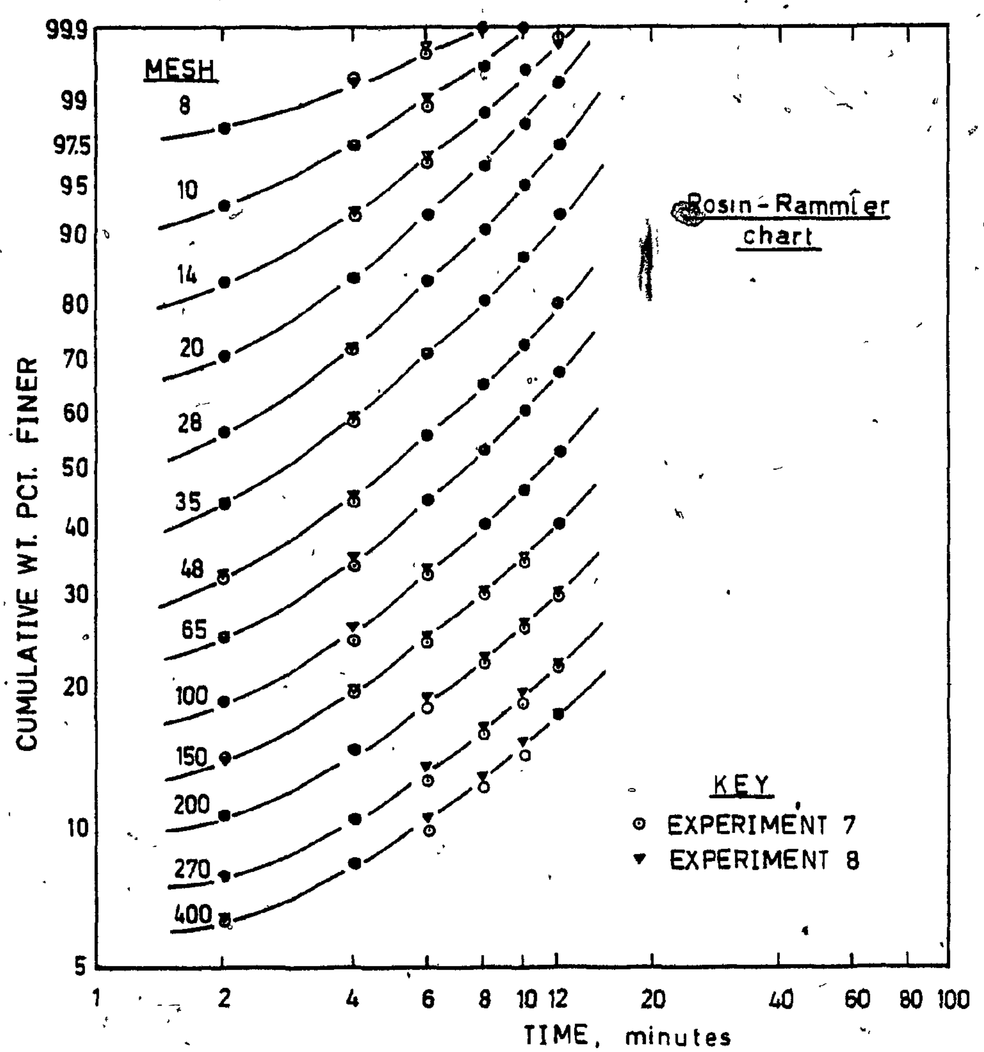
Experiment No.6. Results. p-order plots.



Rosin-Rammler chart
MESH
28
48
100
200
400
EXPERIMENT 6
Cum Wt Pct Finer
TIME, MINUTES

FIGURE 5.12

Experiments No.7 and 8. Results. p-order.



MESH
8
10
14
20
28
35
48
65
100
150
200
270
400
Rosin - Rammler chart
KEY
EXPERIMENT 7
EXPERIMENT 8
CUMULATIVE WT. PCT. FINER
TIME, minutes
99.9
99
97.5
95
90
80
70
60
50
40
30
20
10
5
1
2
4
6
8
10
12
20
40
60
80
100

by experiments 3 to 6. The specific rate-of-breakage was observed to decrease with increased void filling.

Lastly, the top size and single size method grinding kinetics estimation was compared in experiments 4 and 5. The +28# fraction broke more slowly in the single size experiment than in the top size experiment.

5.1.2 Pb-Zn Ore (CUF and RMD)

Splitting Tests

A series of splitting tests using the spinning riffler was performed to assess the sampling (cutting) efficiency. The material tested was the CUF (cyclone underflow) material. Table 5.9 shows the results of one typical test run. These results are the mean, standard deviation and variance of size assays in percent (absolute). The figures reported are considered, in this study, as a measure of the sampling efficiency of the spinning riffler.

Grinding Tests

Sections IV.1.1 and IV.1.2 of Appendix IV, show the computer printouts of the CUF and RMD experimental results. The input data to the program was:

1/ measured screen weights retained (g)

2/ measured chemical assays of Pb, Zn, and Fe (%)

The calculated values were:

1/ size assays (%)

2/ CUM. size assays coarser (%)

TABLE 5.9 Statistical Parameters of Size Assays of the Screening Analysis of Six of the Twelve Samples (50% Sampling) Split on the Spinning Riffler. Materials: CUF.

Tyler Mesh	$\overline{X}$ %	σ %	VAR %
28	8.35	0.16	0.02
35	11.31	0.05	0.00
48	9.98	0.15	0.02
65	9.26	0.11	0.01
100	13.30	0.12	0.01
150	15.24	0.46	0.17
200	10.06	0.58	0.28
270	7.20	0.05	0.00
400	2.82	0.03	0.00
-400	12.44	0.13	0.01

Note:

σ_m = 1.69%

where σ_m is standard deviation of overall weights between split samples.

3/ mineral frequency distributions (%)

4/ overall mean mineral units between grind times

5/ overall standard deviation

6/ adjusted mineral units retained

7/ the first and p-order grind kinetics: $k_{m,i}$, $p_{m,i}$ and $b_{m,i}$

8/ the correlation coefficients of the first and p-order regression analyses

The mean and standard deviation of the computed head assays from the five RMD and seven CUF experiments are given in Table 5.10. Clearly there is little deviation between samples.

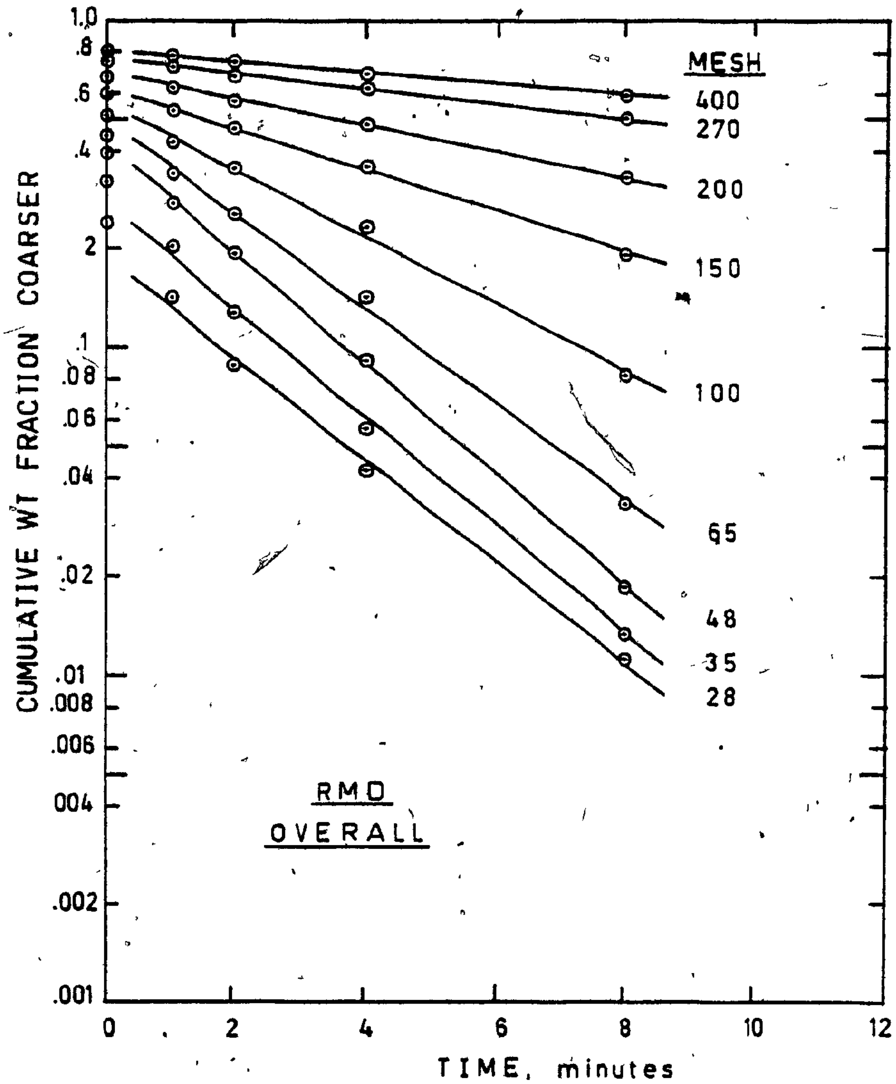
TABLE 5.10 Mean and Standard Deviation of Measured Pb, Zn and Fe Assays for each Grind Time.

Experiment	Mean, %			Standard Deviation, %		
	Pb	Zn	Fe	Pb	Zn	Fe
CUF	5.71	8.95	15.55	0.16	0.16	0.29
RMD	2.04	6.69	8.36	0.24	0.25	0.32

Figures 5.13 to 5.16 show the first order plots for the RMD data and Figures 5.17 to 5.24 show the p-order fit for both CUF and RMD tests. The regression analysis included times up to 6 min only based on an estimation that 6 min represents the maximum residence time which would be encountered in the full-size mill at Pine Point. An

FIGURE 5.13

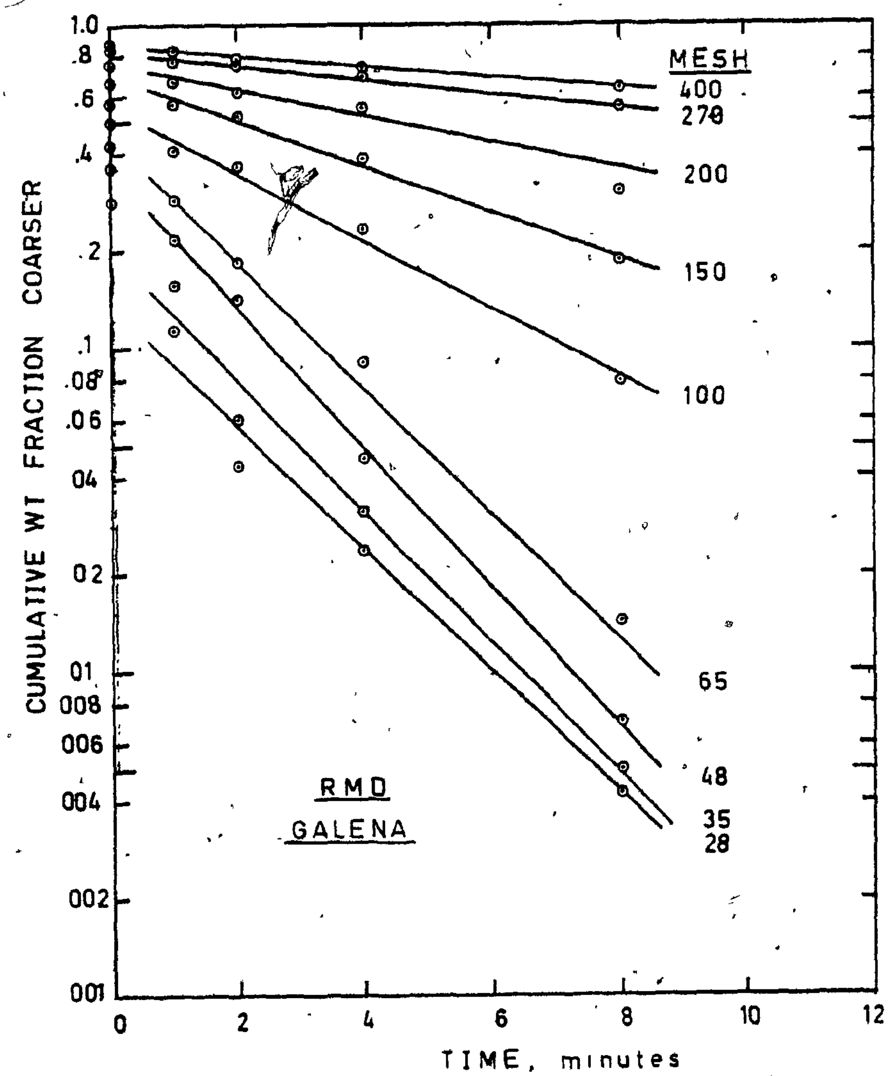
Pb/Zn RMD grinding experiment. Overall results.
First-order plots.



CUMULATIVE WT FRACTION COARSER
1.0
.8
.6
.4
2
.1
.08
.06
.04
.02
.01
.008
.006
004
.002
.001
0
2
4
6
8
10
12
TIME, minutes
MESH
400
270
200
150
100
65
48
35
28
RMD
OVERALL

FIGURE 5.14

Pb/Zn RMD grinding experiment. Galena (PbS) results. First-order plots.



CUMULATIVE WT FRACTION COARSER
TIME, minutes
MESH
400
270
200
150
100
65
48
35
28
RMD
GALENA
1.0
.8
.6
.4
.2
.1
.08
.06
.04
.02
.01
.008
.006
.004
.002
.001
0
2
4
6
8
10
12

FIGURE 5.15

Pb/Zn RMD grinding experiment. Sphalerite (ZnS) results. First-order plots.

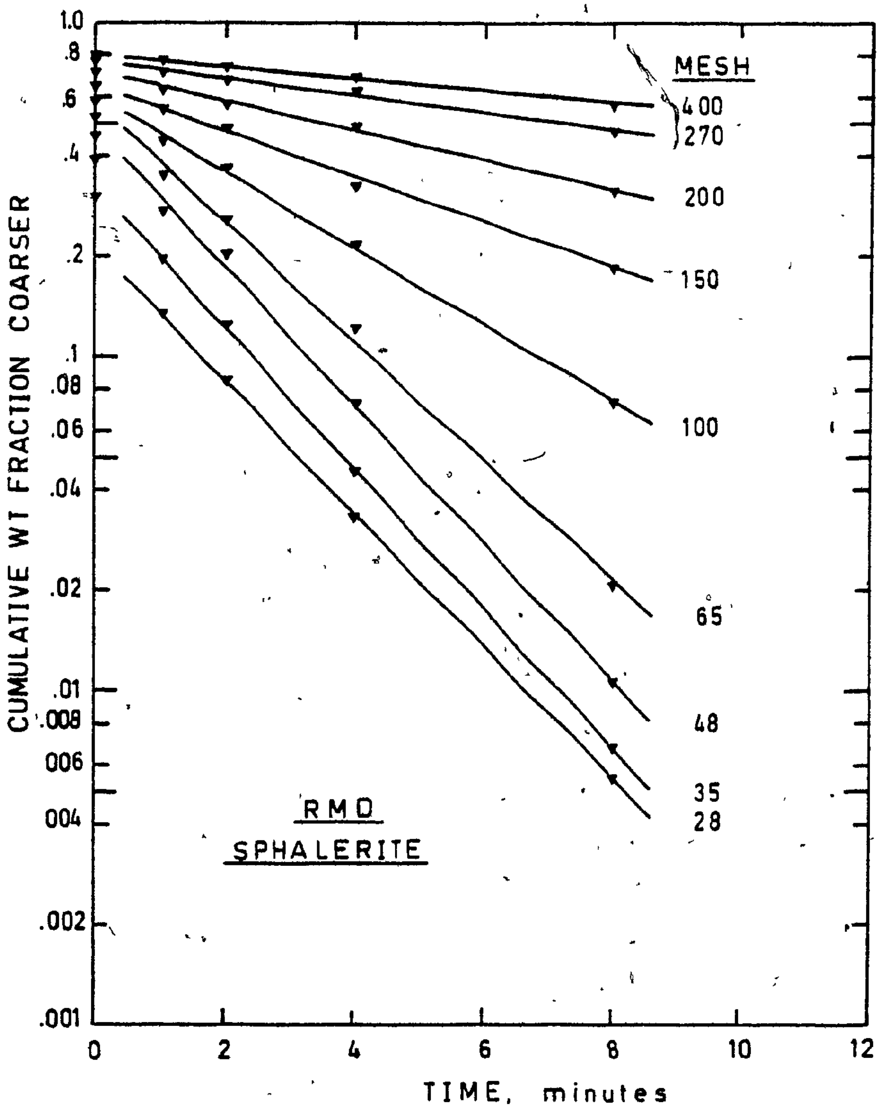
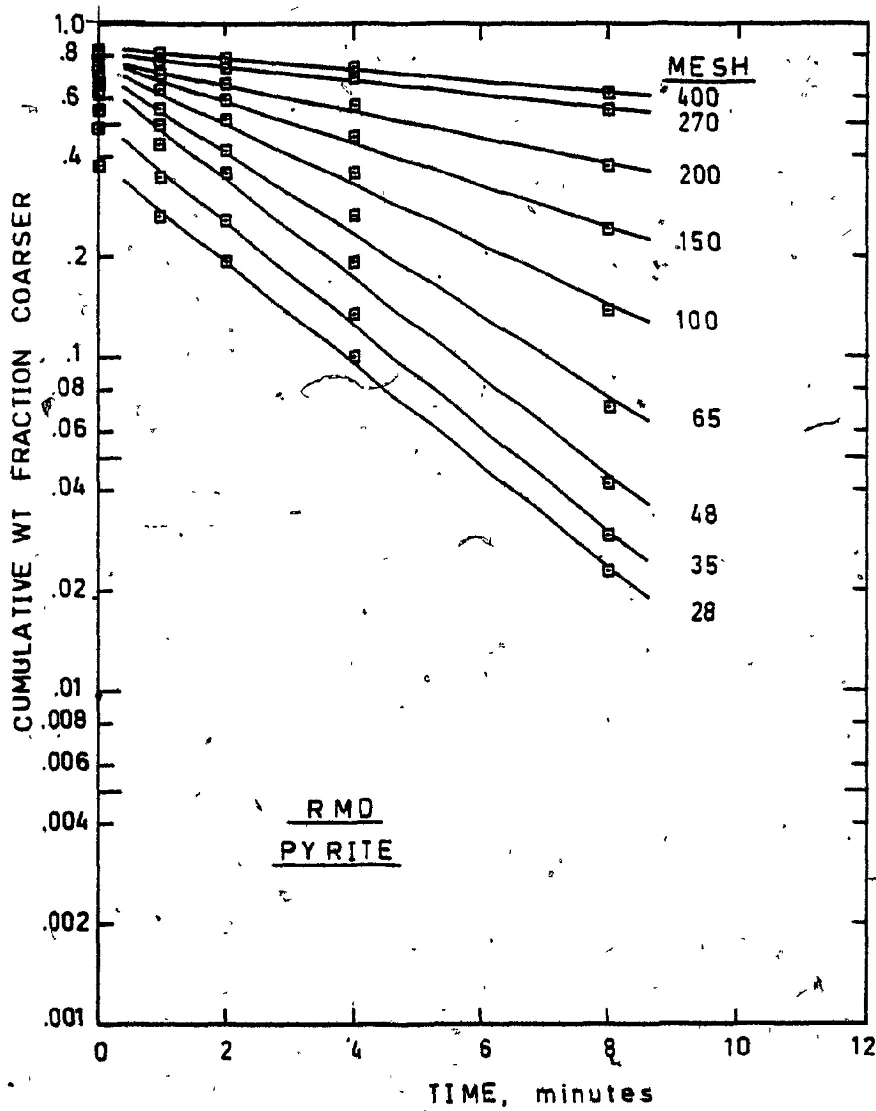

CUMULATIVE WT FRACTION COARSER
TIME, minutes
MESH
400
270
200
150
100
65
48
35
28
RMD
SPHALERITE
1.0
.8
.6
.4
.2
.1
.08
.06
.04
.02
.01
.008
006
004
.002
.001
0
2
4
6
8
10
12

FIGURE 5.16

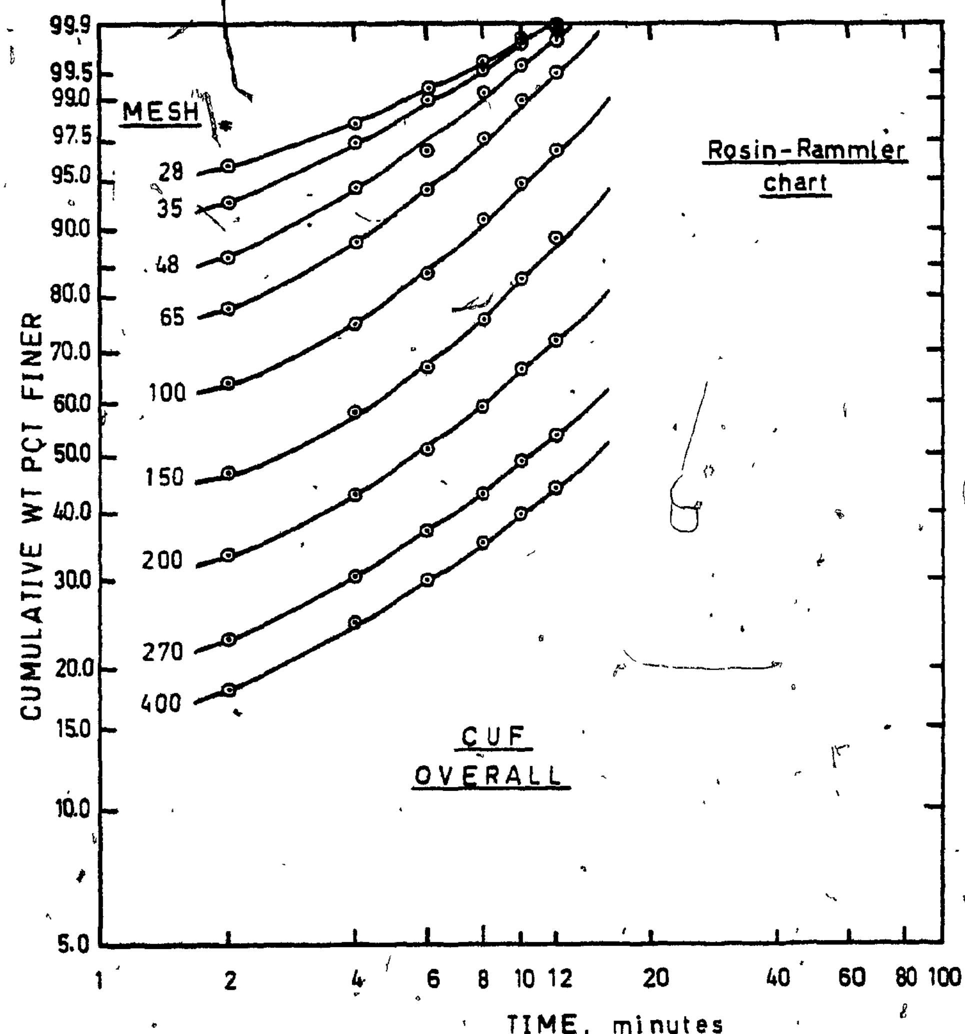
Pb/Zn RMD grinding experiment. Pyrite (FeS_2) results. First-order plots.



CUMULATIVE WT FRACTION COARSER
1.0
.8
.6
.4
.2
.1
.08
.06
.04
.02
.01
.008
.006
.004
.002
.001
0
2
4
6
8
10
12
TIME, minutes
MESH
400
270
200
150
100
65
48
35
28
RMD
PYRITE

FIGURE 5.17

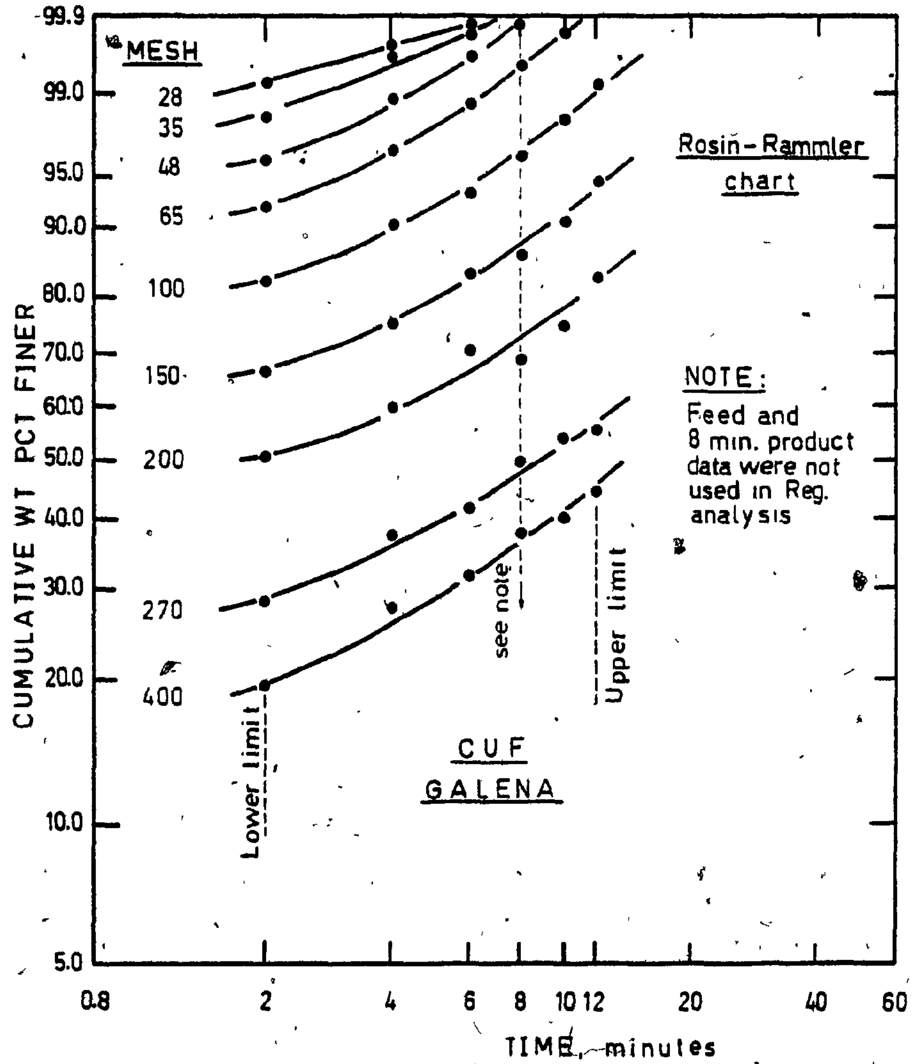
Pb/Zn CUF grinding experiment: Overall results. p-order plots.



MESH
28
35
48
65
100
150
200
270
400
Rosin-Rammler chart
CUF OVERALL
CUMULATIVE WT PCT FINER
99.9
99.5
99.0
97.5
95.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
15.0
10.0
5.0
1
2
4
6
8
10
12
20
40
60
80
100
TIME, minutes

FIGURE 5.18

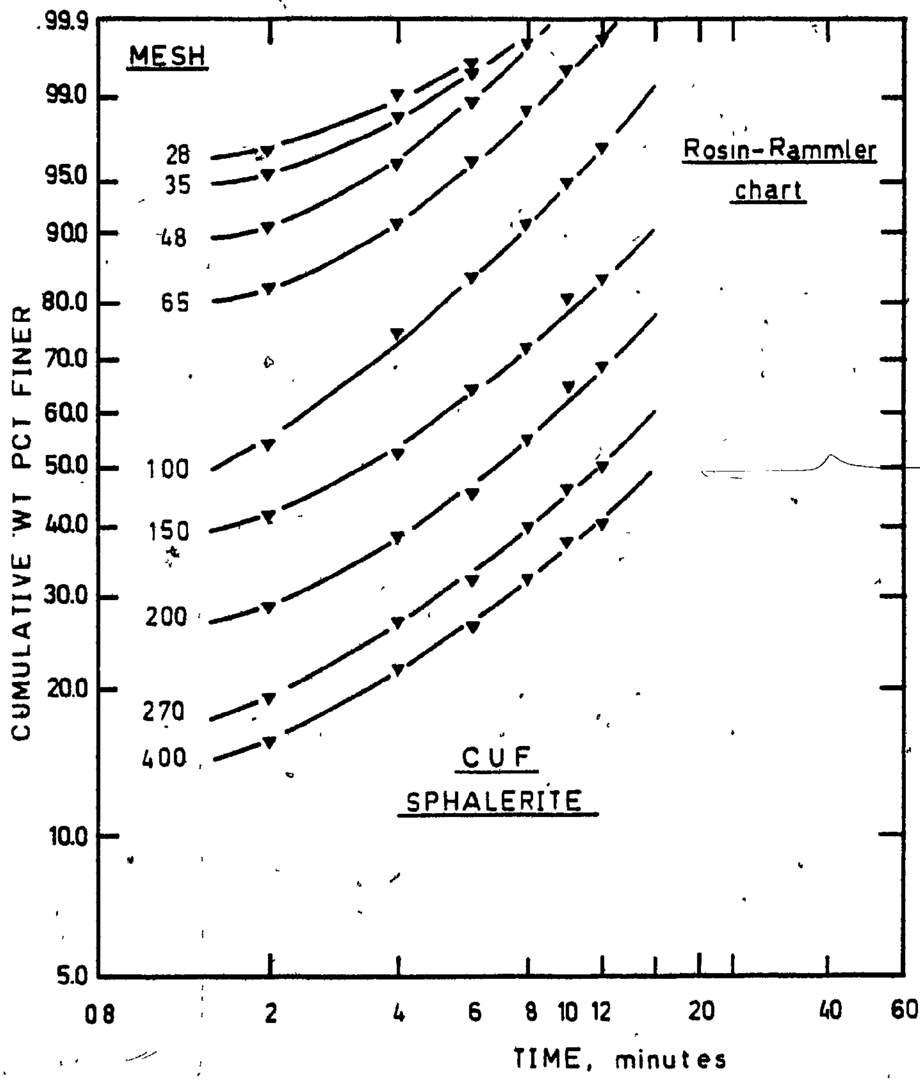
Pb/Zn CUF grinding experiment. Galena (PbS) results. p-order plots.



MESH
28
35
48
65
100
150
200
270
400
99.9
99.0
95.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
5.0
CUMULATIVE WT PCT FINER
0.8
2
4
6
8
10 12
20
40
60
TIME, minutes
Rosin-Rammler chart
NOTE:
Feed and 8 min. product data were not used in Reg. analysis
see note
Upper limit
Lower limit
CUF GALENA

FIGURE 5.19

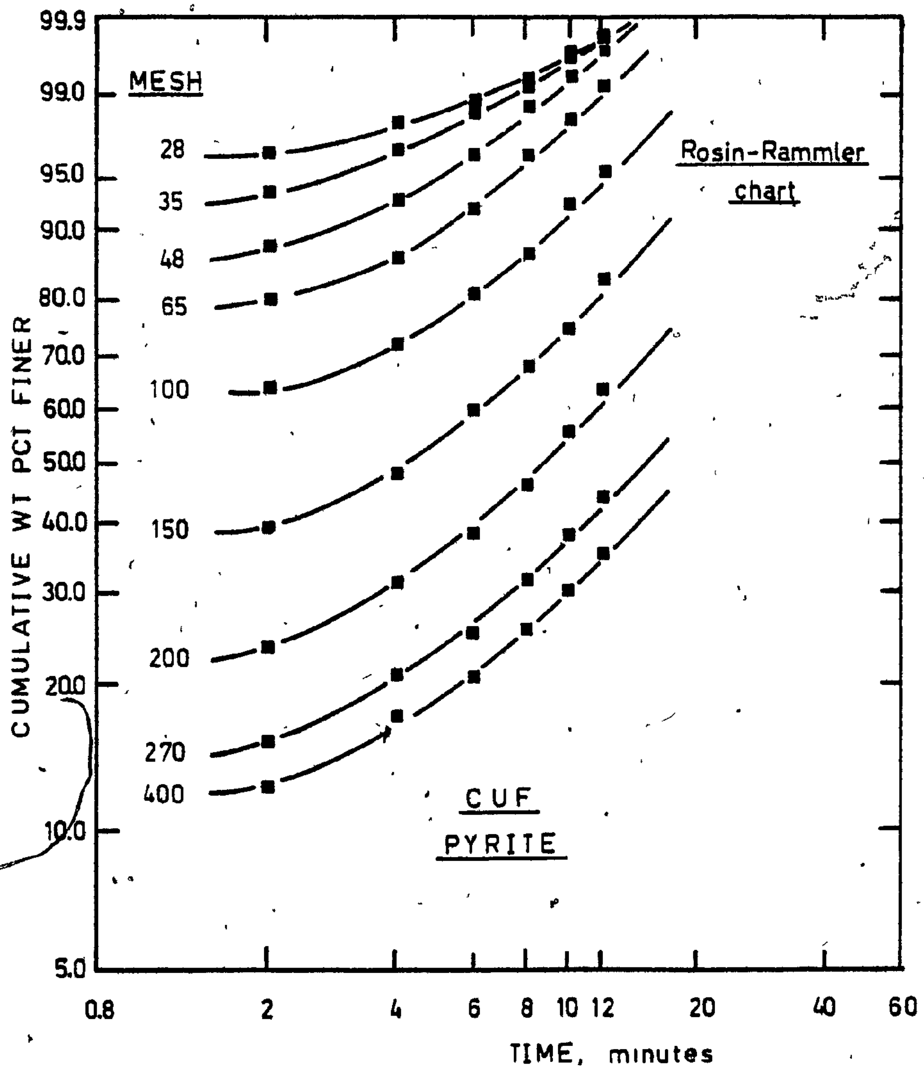
Pb/Zn CUF grinding experiment. Sphalerite (ZnS) results. p-order plots.



MESH
28
35
48
65
100
150
200
270
400
Rosin-Rammler chart
CUF SPHALERITE
CUMULATIVE WT PCT FINER
99.9
99.0
95.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
5.0
08
2
4
6
8
10
12
20
40
60
TIME, minutes

FIGURE 5.20

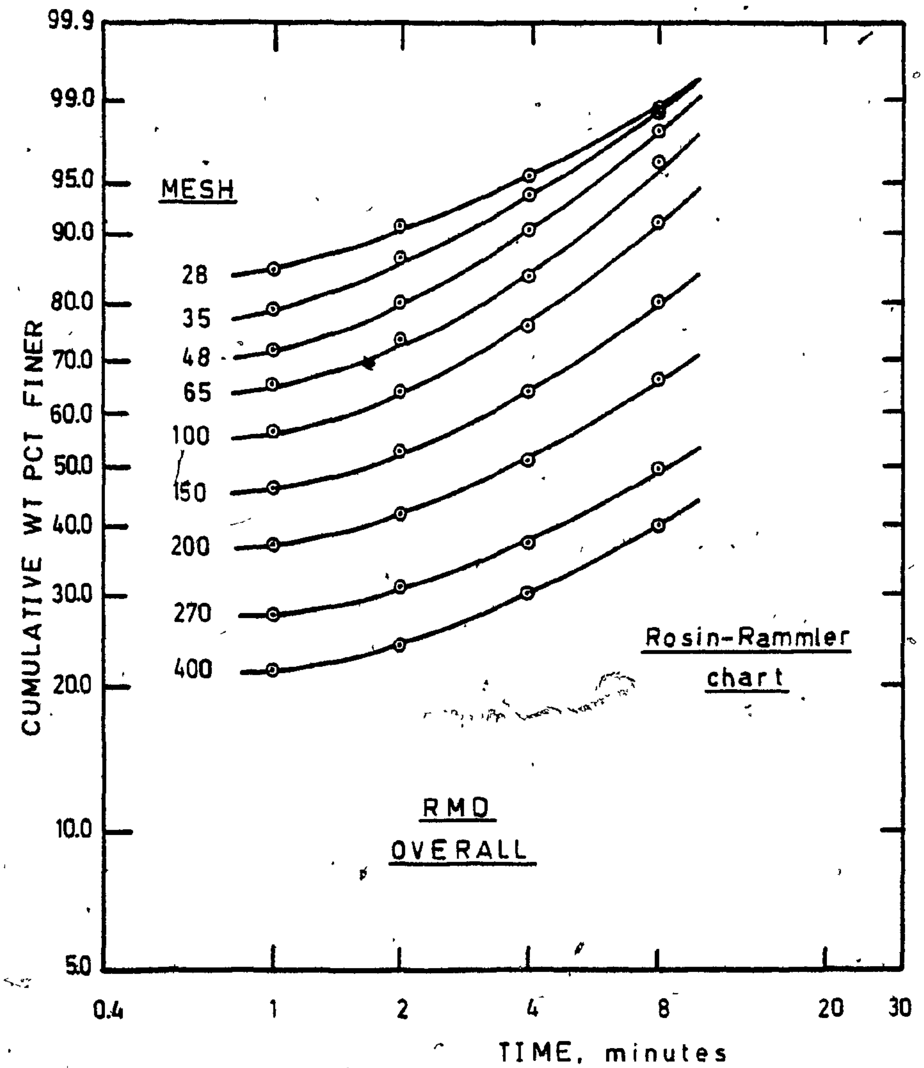
Pb/Zn CUF grinding experiment. Pyrite (FeS_2) results. p-order plots.



99.9
99.0
95.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
5.0
CUMULATIVE WT PCT FINER
MESH
28
35
48
65
100
150
200
270
400
Rosin-Rammler chart
CUF PYRITE
0.8
2
4
6
8
10
12
20
40
60
TIME, minutes

FIGURE 5.21

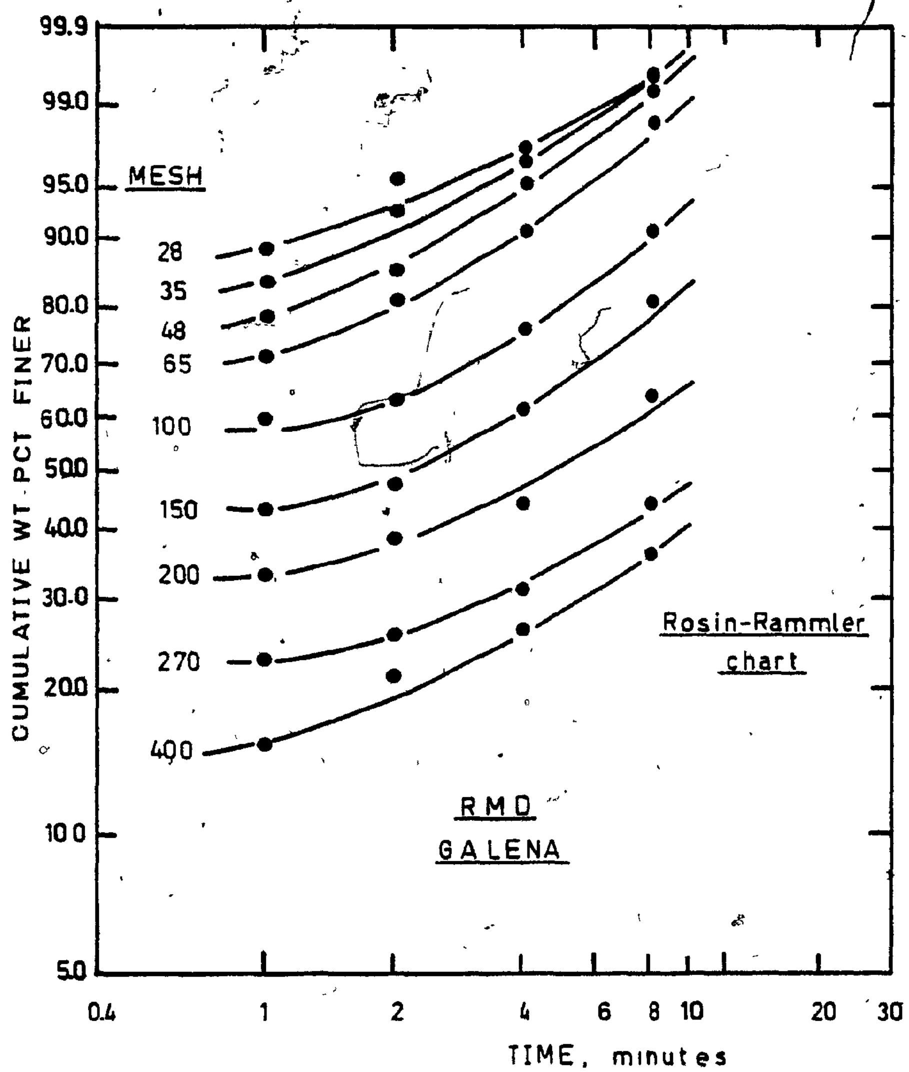
Pb/Zn RMD grinding experiment. Overall results.
p-order plots.



99.9
99.0
95.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
5.0
CUMULATIVE WT PCT FINER
MESH
28
35
48
65
100
150
200
270
400
Rosin-Rammler chart
RMD OVERALL
0.4
1
2
4
8
20
30
TIME, minutes

FIGURE 5.22

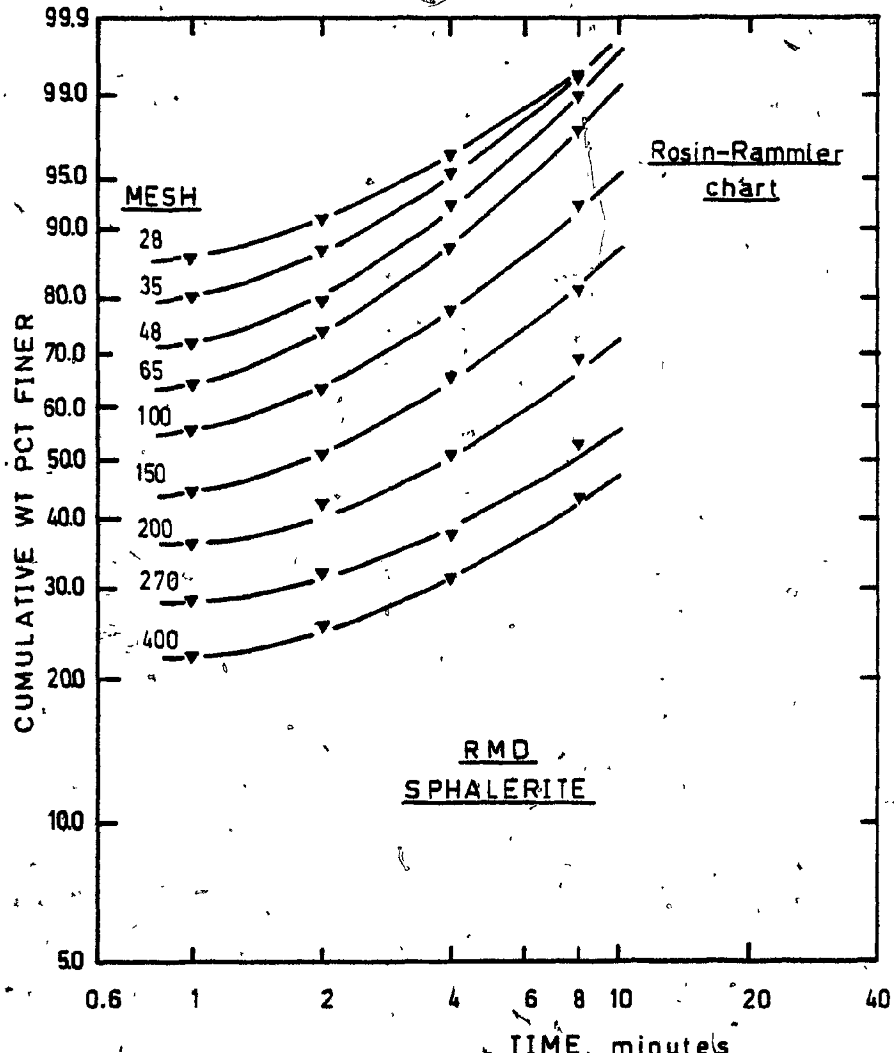
Pb/Zn RMD grinding experiment. Galena (PbS) results. p-order plots.



99.9
99.0
95.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
5.0
CUMULATIVE WT. PCT. FINER
MESH
28
35
48
65
100
150
200
270
400
Rosin-Rammler chart
RMD
GALENA
0.4
1
2
4
6
8
10
20
30
TIME, minutes

FIGURE 5.23

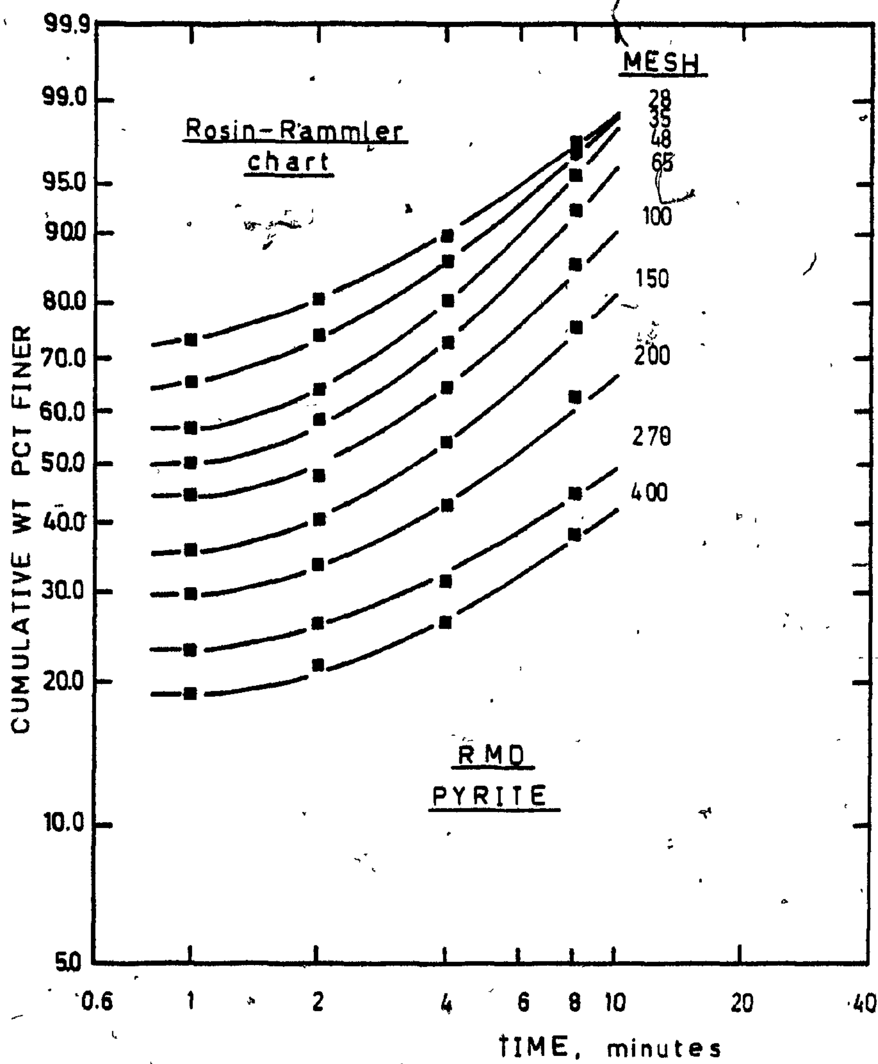
Pb/Zn RMD grinding experiment. Sphalerite (ZnS) results. p-order plots.



99.9
99.0
95.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
5.0
CUMULATIVE WT PCT FINER
MESH
28
35
48
65
100
150
200
270
400
Rosin-Rammler chart
RMD
SPHALERITE
0.6
1
2
4
6
8
10
20
40
TIME, minutes

FIGURE 5.24

Pb/Zn RMD grinding experiment. Pyrite (FeS_2) results. p-order plots.


Rosin-Rammler chart
MESH
28
35
48
65
100
150
200
270
400
RMD PYRITE
CUMULATIVE WT PCT FINER
99.9
99.0
95.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
5.0
0.6
1
2
4
6
8
10
20
40
TIME, minutes

accurate fit over this time was felt necessary rather than over all time. Nevertheless, as Figures 5.17 to 5.24 show, for the p-order model, extrapolation to longer times was possible.

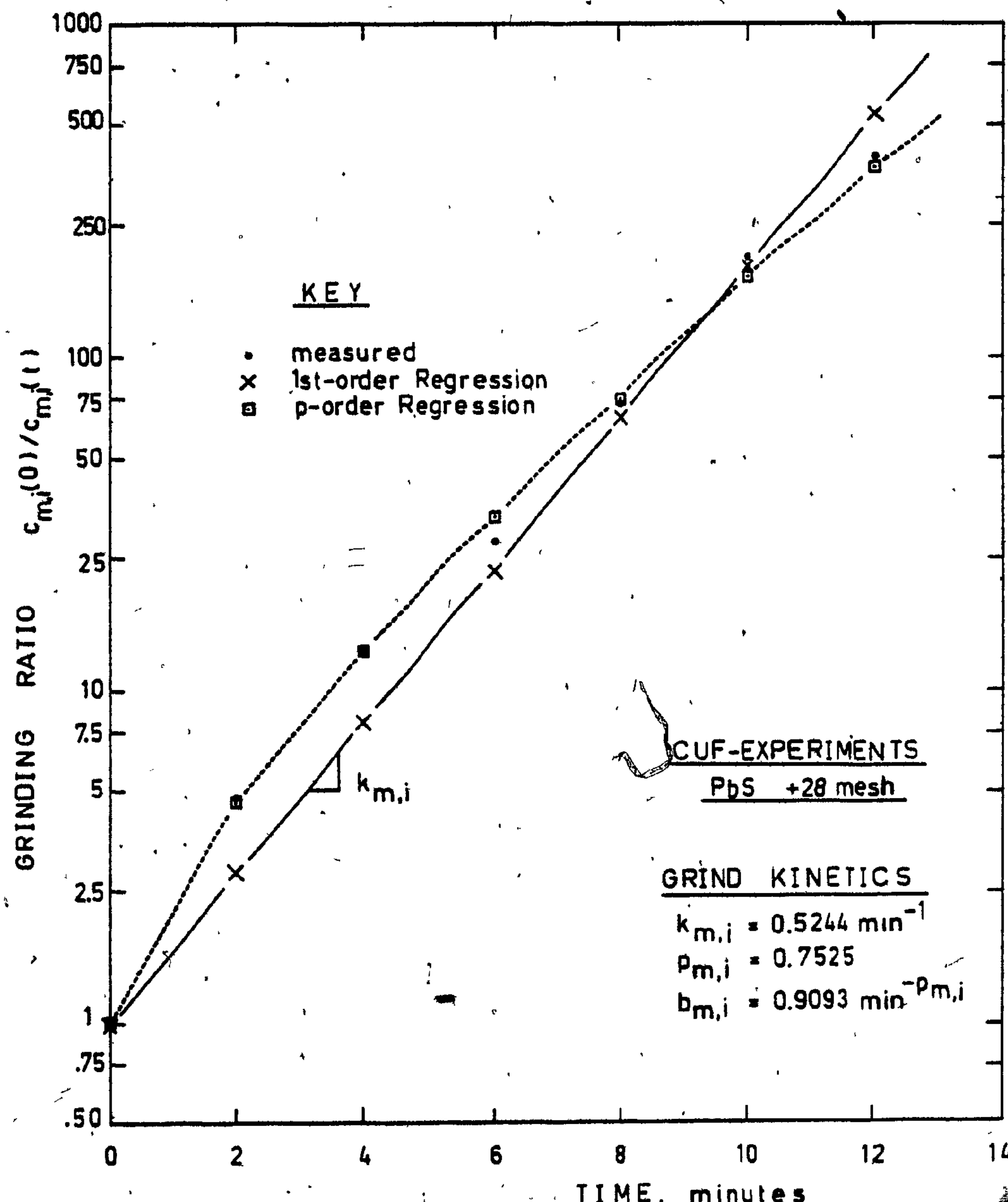
It should be noted that the p-order regression results of CUF, size fractions 150 and 200# (Appendix IV, Section IV.1.1) gave the physically impossible result that $b_{PbS,150\#}$ (0.043) is less than $b_{PbS,200\#}$ (0.0919). To overcome future problems in simulating the grinding circuit using this data, a new regression analysis was performed omitting these two points.

Figures 5.13 to 5.16 show that first order is a relatively poor fit to the data, especially for the coarser fractions, with the possible exception of pyrite. Although not shown, first order plots for the CUF material were equally poor. On the other hand, the p-order fit is extremely successful over the entire size, mineral and time range. To illustrate the success, Figure 5.25 shows the p-order and first order fits for + 28 mesh galena from CUF. The p-order fits the observed curvature extremely closely, especially considering the expanded ordinate scale with this plot.

Figure 5.26 shows the instantaneous rates-of-breakage of overall, PbS, ZnS, FeS_2 and calcite-dolomite. The plots are for the CUF and RMD grind experiments. The grind time utilized is 3.26 min, corresponding to the simulated steady state residence time of the 154.2 mtph throughput. The equation used to calculate the instantaneous rates-of-breakage is Equation (2.1.15).

FIGURE 5.25

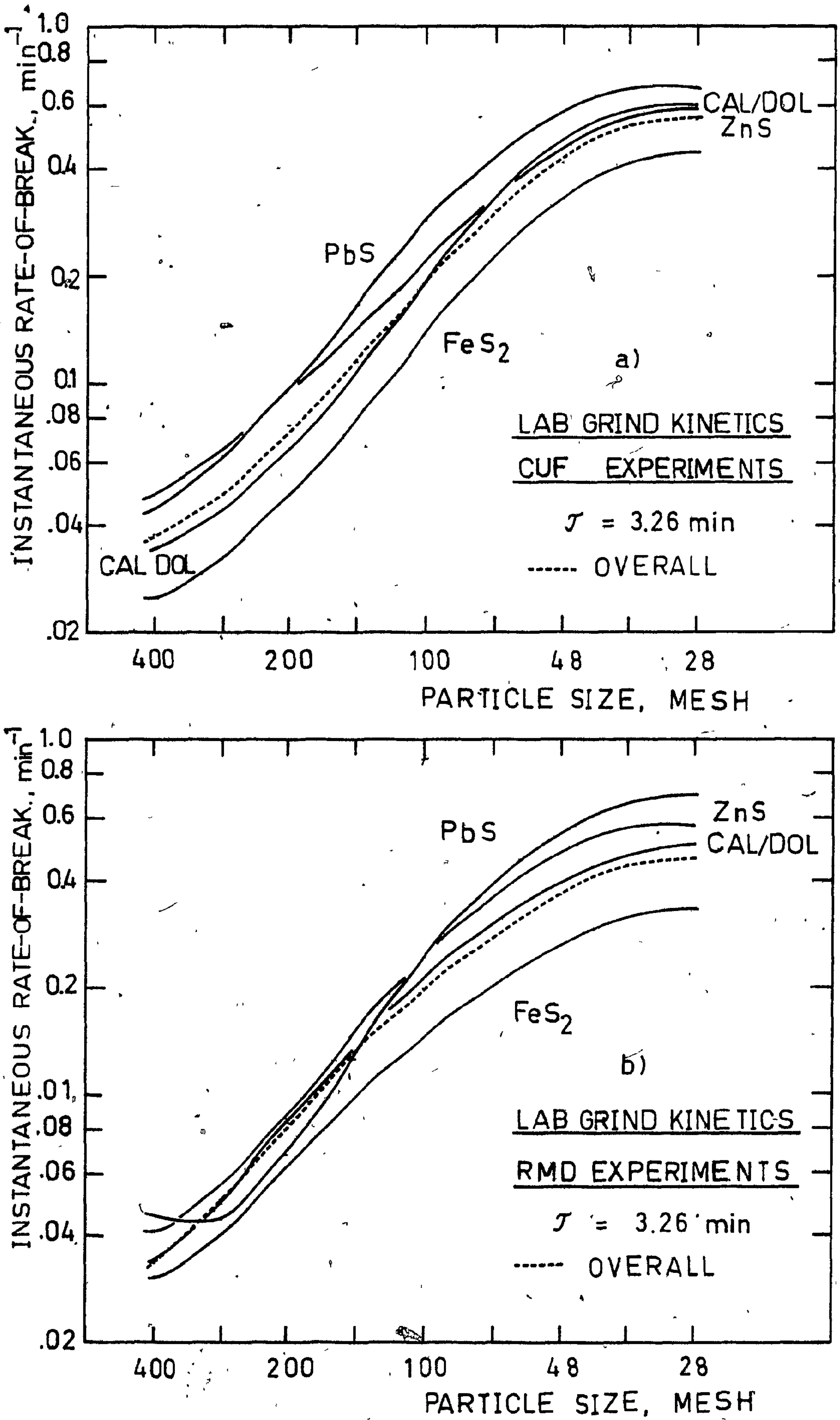
Pb/Zn CUF grinding experiment. Galena (PbS), +28 mesh fraction. Plotting of the grinding ratio $C_{m,i}(0)/C_{m,i}(t)$ vs. time on a semi-log scale chart. The graph shows the measured and the first and p-order regression data points.



KEY
measured
1st-order Regression
p-order Regression
GRINDING RATIO $c_{m,i}(0)/c_{m,i}(t)$
TIME, minutes
$k_{m,i}$
CUF-EXPERIMENTS
PbS +28 mesh
GRIND KINETICS
$k_{m,i}$ = 0.5244 min^{-1}
$p_{m,i}$ = 0.7525
$b_{m,i}$ = 0.9093 $min^{-p_{m,i}}$

FIGURE 5.26

Pb/Zn lab grinding experiments. Overall and mineral-by-mineral instantaneous rate-of-breakage vs. particle size at $\tau = 3.26$ min.
a) CUF experiments; b) RMD experiments.


INSTANTANEOUS RATE-OF-BREAK., min^{-1}
1.0
0.8
0.6
0.4
0.2
0.1
.08
.06
.04
.02
400
200
100
48
28
PARTICLE SIZE, MESH
PbS
CAL/DOL
ZnS
FeS$_2$
CAL DOL
a)
LAB GRIND KINETICS
CUF EXPERIMENTS
$\mathcal{T}$ = 3.26 min
------ OVERALL
PbS
ZnS
CAL/DOL
FeS$_2$
b)
LAB GRIND KINETICS
RMD EXPERIMENTS
$\mathcal{T}$ = 3.26 min
------ OVERALL

The instantaneous rates-of-breakage are similar for both samples and reveal an S-shape curvature from $k_{m,i} \sim 0.02$ to ~ 0.07 min^{-1}. Note that pyrite exhibits consistently the lowest rate-of-breakage and PbS usually the highest, except at the finer sizes.

5.1.3 Flotation Model

Data was available for the flotation recovery matrix, $YC_{m,i}$ from tests on ore and ball mill discharge samples. Data based on ball mill discharge samples was selected for the simulation. Figure 5.27 shows the data used, which is typical of these tests. The overall recovery and flotation conditions accompany the figure. The 3 min flotation time was specified by Pine Point for design purposes. The actual data matrix employed is given in Appendix V, Section V.3.1 and V.3.2.

5.2 Plant

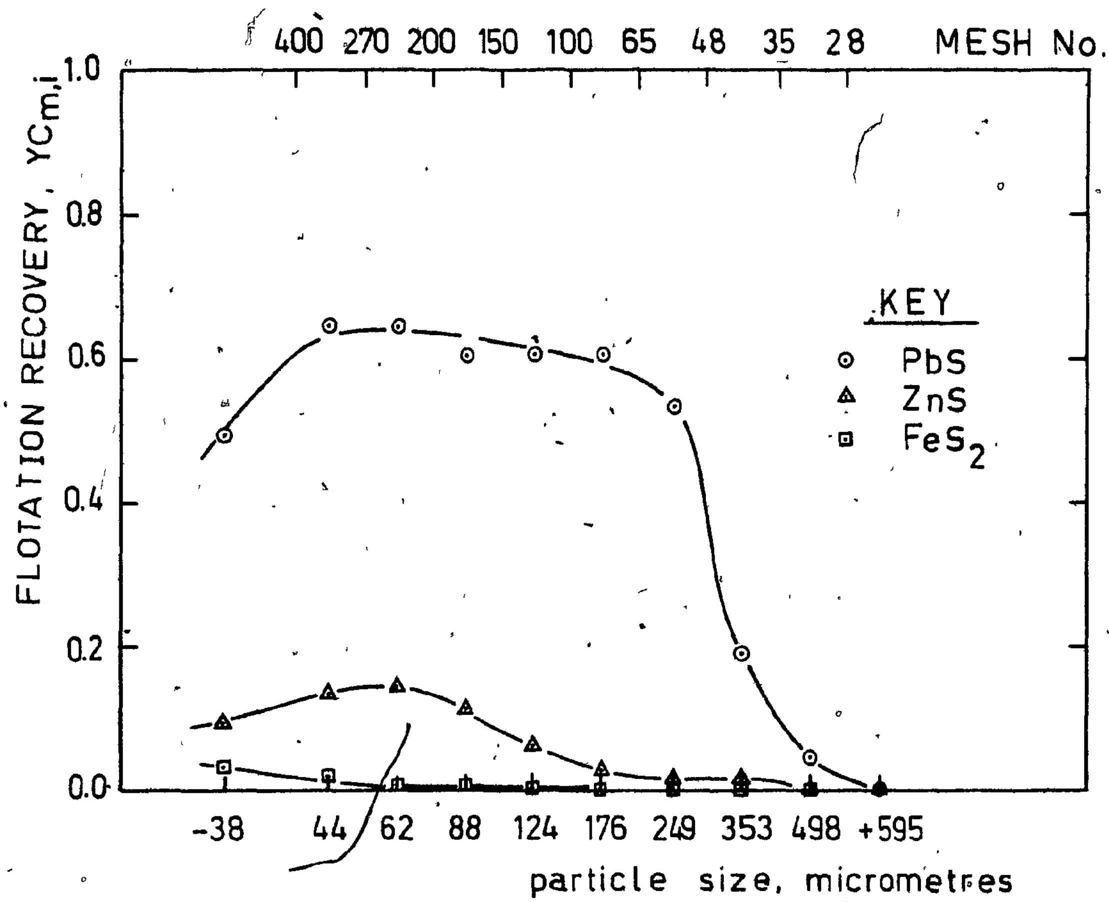
5.2.1 Plant Data Adjustment

Two sets of samples were available to ascertain the grind circuit performance. One set was for 154.2 tonne/hr and the other for the 190.3 tonne/hr throughput. This represents about the maximum range of operation at Pine Point. A sample was obtained from each of the five streams of the circuit. Size and chemical assays were determined; this is the raw data to be adjusted.

The adjustments were performed using the computer program of Appendix IV, Section IV.2. Section IV.2.1 is the printout for the 154.2 mtph case, whilst Section IV.2.2 reports the 190.3 mtph case. Both

FIGURE 5.27

Pb/Zn BMD lab flotation experiment results.
Mineral-by-mineral recoveries vs. particle size.



weight sample, g

head	11 005
conc	710
tails	10 295

percent Pb

head	9.7
conc	76.1
tails	5.1
Pb recovery, PCT	50.7

percent Zn

head	5.4
conc	4.7
tails	5.5
Zn recovery, PCT	5.6

percent Fe

head	8.4
conc	1.0
tails	8.9
Fe recovery, PCT	0.8

cell volume	5 lt
pulp dilution	60% by wt.
pH	10
flotation time	3 min

reagents

CX-31, 1% (collector)	0.13 lbs/sh.ton
MIBC, 100% (frother)	0.02
$ZnSO_4$, 1% (Zn depress.)	0.27
CaO (pH modifier)	

results are presented in tabular form, showing the raw data (unadjusted) and the adjusted data (size and chemical assays in percent). Also shown is the overall and mineral-by-mineral mass ratio of cyclone feed to overflow, i.e. (1 + CL).

The adjustments are small for the size assays data and relatively higher for the mineral assay data. Table 5.11 gives a measure of the standard error (absolute) for the size and mineral assays in the COF for the two tonnages.

Note that $\hat{S}_{m,i}$ and $S_{m,i}$ are not the adjusted percent mineral assays calculated with the Lagrangian method. They have been calculated from the following equations:

$$S_{m,i} = \text{factor}_m(\text{size}_{m,i} \cdot \text{chem}_{m,i})_{\text{unadjusted}}/100 \qquad (5.1)$$

$$\hat{S}_{m,i} = \text{factor}_m(\text{size}_{m,i} \cdot \text{chem}_{m,i})_{\text{adjusted}}/100 \qquad (5.2)$$

where $\text{size}_{m,i}$ and $\text{chem}_{m,i}$ are percent size and mineral assays, respectively; and factor_m is the stoichiometric factor to convert chemical to mineral assays.

The standard errors calculated in this way reflect the weighted effect of the adjustment on the mineral assays.

TABLE 5.11 S_e, Standard Error of Size and Mineral Assays in Percent (Absolute). Stream: Cyclone Overflow (COF).

Item	Standard Error	
	154.2 mtph	190.3 mtph
size	0.26	0.19
PbS	0.08	0.05
ZnS	0.16	0.02
FeS_2	0.69	0.19

S_e Calculations:

size: $$S_e = \left\{\frac{\sum_{i=1}^{n}(\hat{S}_i - S_i)^2}{n-1}\right\}^{1/2}$$

mineral: $$S_e = \left\{\frac{\sum_{i=1}^{n}(\hat{S}_{m,i} - S_{m,i})^2}{n-1}\right\}^{1/2}$$

where: $\hat{S}_i$ and S_i are adjusted and unadjusted PCT size assays, respectively.

$\hat{S}_{m,i}$ and $S_{m,i}$ are adjusted and unadjusted percent mineral assays, respectively.

5.2.2 Cyclone Model

$Y_{m,i}$ Matrix

The cyclone selectivity index $Y_{m,i}$ values are also calculated by the program of Section IV.2. The printouts give the unadjusted and adjusted $Y_{m,i}$ for 154.2 and 190.3 mtph tonnages.

Combined Model

A graphical representation of the Plitt Model of the cyclone classification curve is shown in Figure 5.28 to Figure 5.31 for both cases, 154.2 and 190.3 mtph. The Plitt Equation is:

$$Y'_{m,i} = 1. - \exp\{-0.693(d/d_{50(C)m})^{n_m}\} \qquad (2.2.5)$$

where: $Y_{m,i}$ is calculated by means of the following equation:

$$Y'_{m,i} = (Y_{m,i} - a_m)/(1 - a_m) \qquad (2.2.4)$$

Tables 5.12 and 5.13 show $Y'_{m,i}$; $d_{50(C)m}$; and a_m and n_m of the 154.2 and 190.3 mtph cases, respectively. The Finch/Matwijenko model relating $d_{50(C)m}$ to mineral density is:

$$\ln\{d_{50(C)m}\} = -K_1 \ln\{(\rho_m - \rho_\ell)\} + K_2 \qquad (2.2.7)$$

Figure 5.32 shows the plots of $\ln\{d_{50(C)m}\}$ vs. $\ln\{\rho_m - 1\}$ on a log-log scale chart. The regression lines ① and ② in the figure are defined by the following equations:

FIGURE 5.28

Plant derived cyclone performance curves at 154.2 mtph. Minerals: galena, sphalerite, pyrite and calcite/dolomite. a) selectivity index $Y_{m,i}$ vs. particle size; b) classification index $Y'_{m,i}$ vs. particle size.

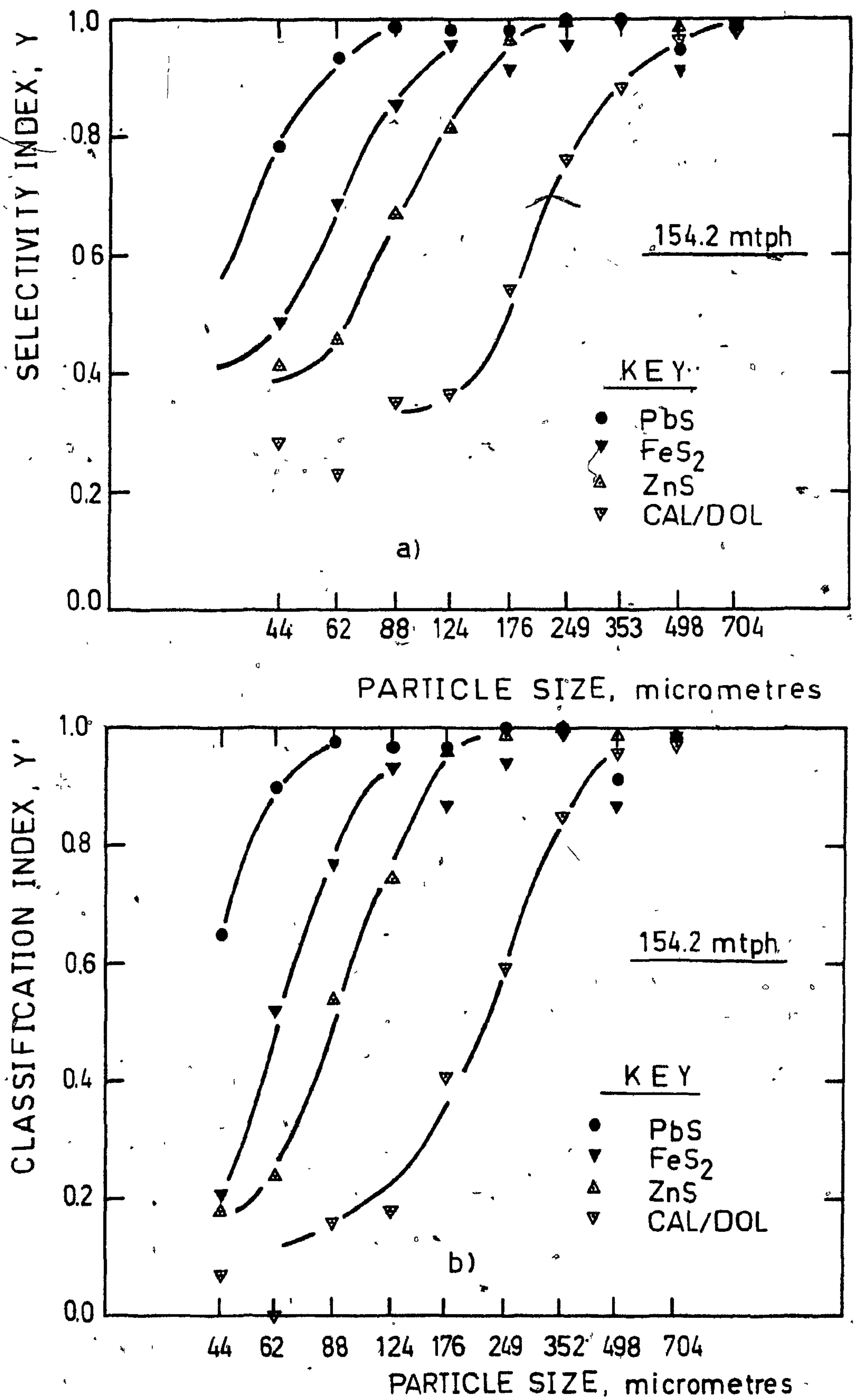
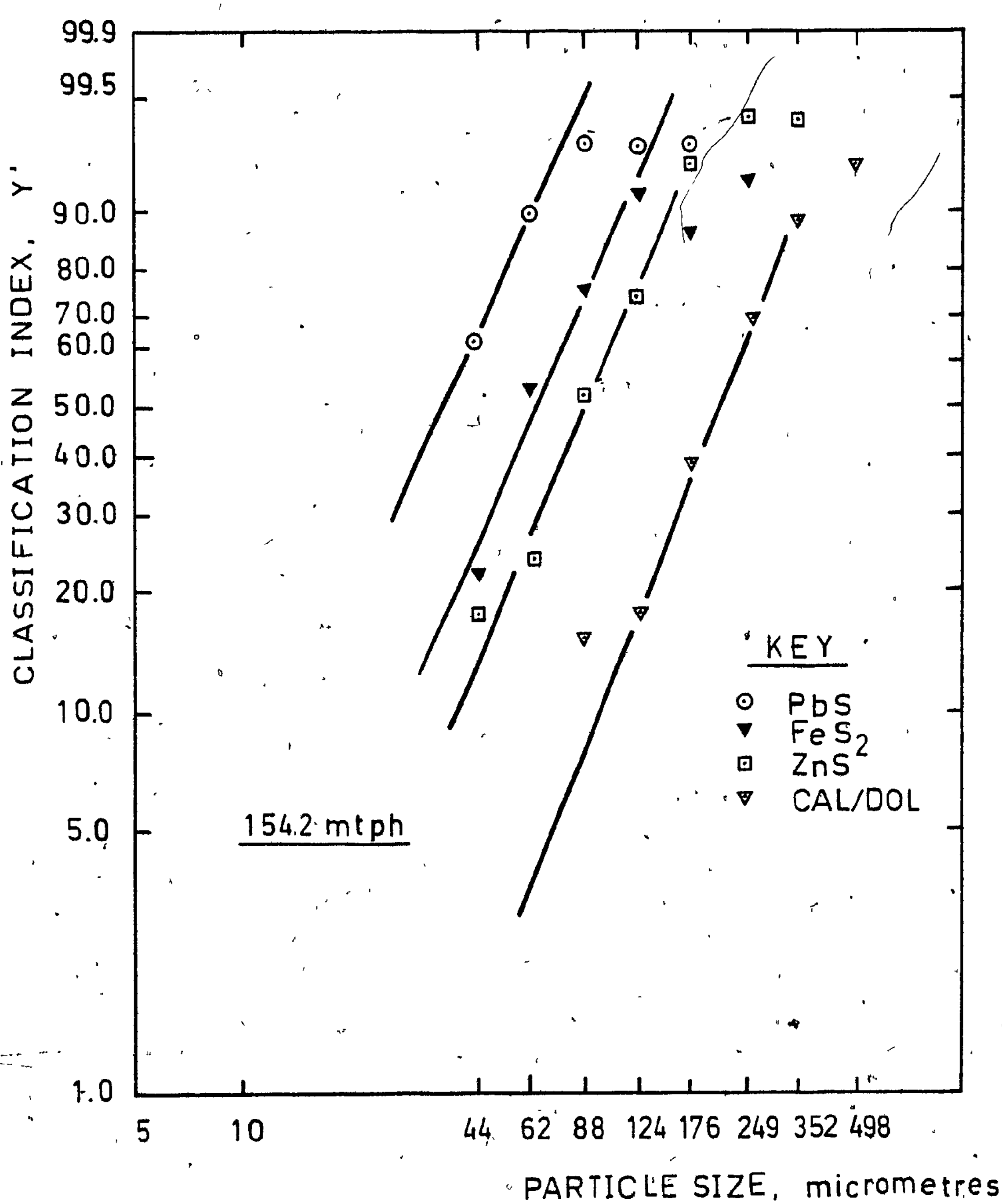

1.0
0.8
0.6
0.4
0.2
0.0
SELECTIVITY INDEX, Y
154.2 mtph
KEY
PbS
FeS2
ZnS
CAL/DOL
a)
44
62
88
124
176
249
353
498
704
PARTICLE SIZE, micrometres
1.0
0.8
0.6
0.4
0.2
0.0
CLASSIFICATION INDEX, Y'
154.2 mtph
KEY
PbS
FeS2
ZnS
CAL/DOL
b)
44
62
88
124
176
249
352
498
704
PARTICLE SIZE, micrometres

FIGURE 5.29

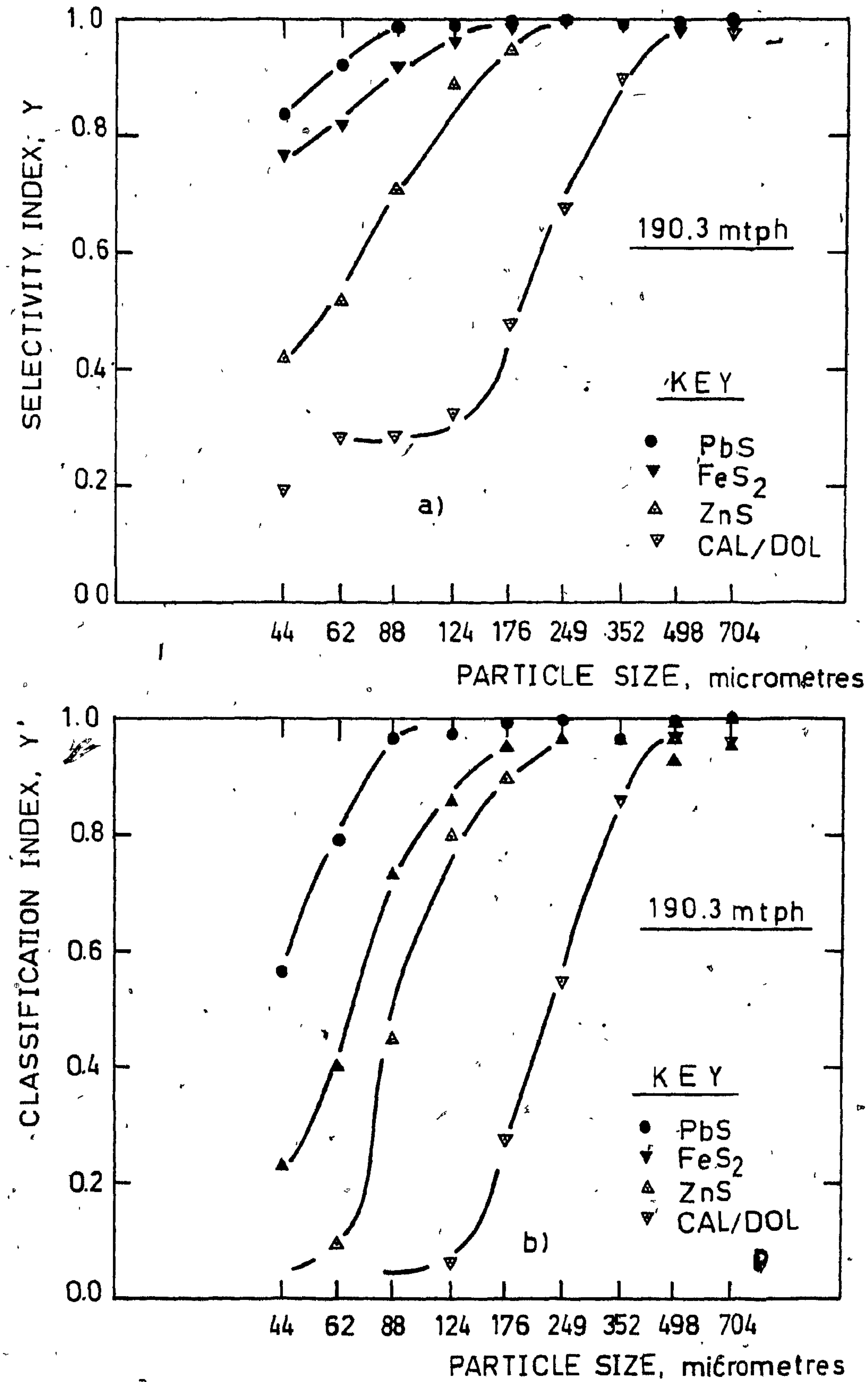
Plant derived cyclone performance curves at 154.2 mtph. Minerals: galena, sphalerite, pyrite and calcite/dolomite. Classification index $Y'_{m,i}$ vs. particle size. Rosin-Rammler chart.



CLASSIFICATION INDEX, Y'
99.9
99.5
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
5.0
1.0
5
10
44
62
88
124
176
249
352
498
PARTICLE SIZE, micrometres
154.2 mtph
KEY
PbS
FeS_2
ZnS
CAL/DOL

FIGURE 5.30

Plant derived cyclone performance curves at 190.3 mtph. Minerals: galena, sphalerite, pyrite and calcite/dolomite. a) selectivity index $Y_{m,i}$ vs. particle size; b) classification index $Y'_{m,i}$ vs. particle size.



1.0
0.8
0.6
0.4
0.2
0.0
SELECTIVITY INDEX, Y
190.3 mtph
KEY
PbS
FeS2
ZnS
CAL/DOL
a)
44 62 88 124 176 249 352 498 704
PARTICLE SIZE, micrometres
CLASSIFICATION INDEX, Y'
190.3 mtph
KEY
PbS
FeS2
ZnS
CAL/DOL
b)
PARTICLE SIZE, micrometres

FIGURE 5.31

Plant derived cyclone performance curves at 190.3 mtph. Minerals: galena, sphalerite, pyrite and calcite/dolomite. Classification index $Y'_{m,i}$ vs. particle size. Rosin-Rammler chart.

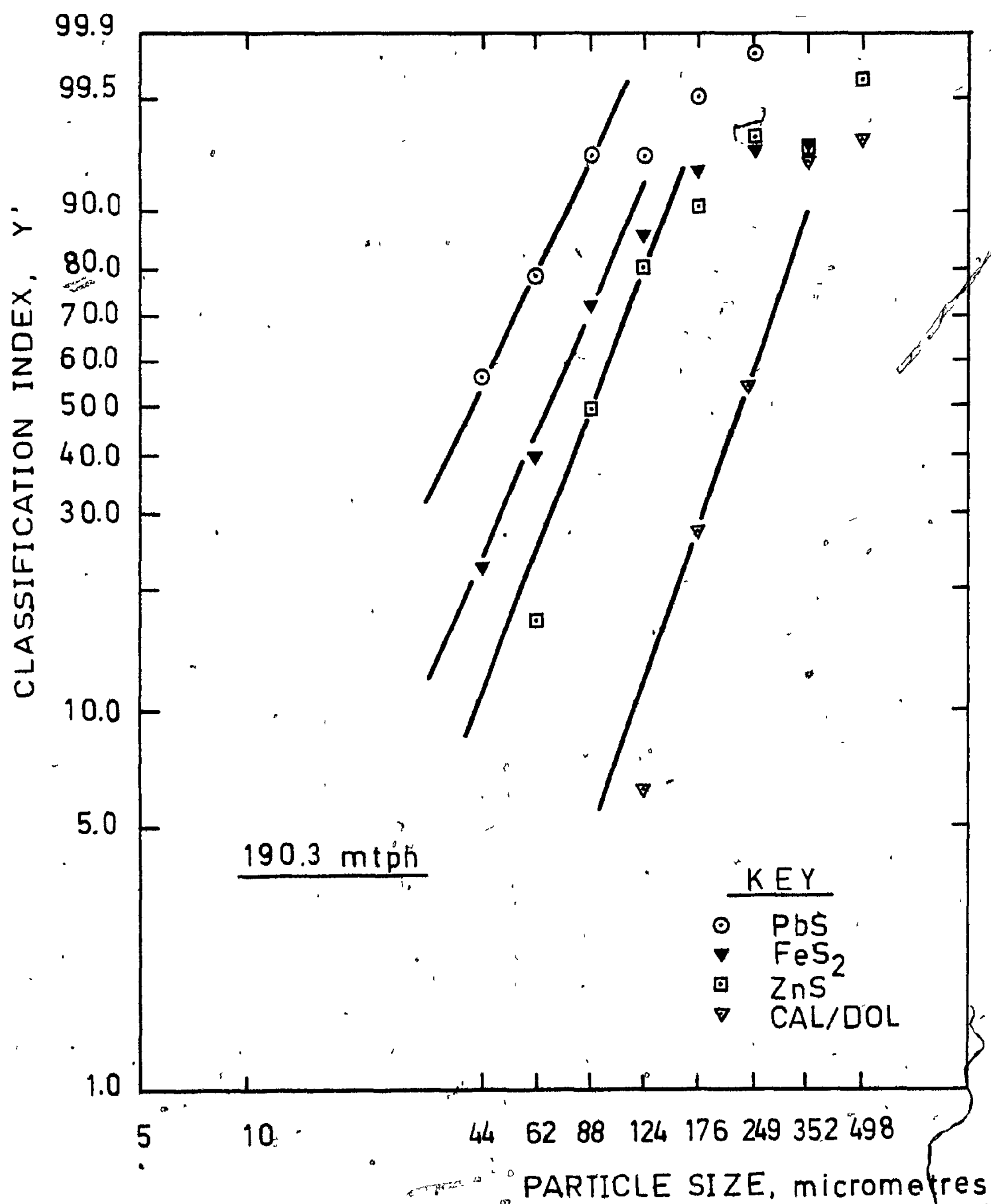

CLASSIFICATION INDEX, Y'
99.9
99.5
90.0
80.0
70.0
60.0
50.0
40.0
30.0
10.0
5.0
1.0
190.3 mtph
KEY
PbS
FeS2
ZnS
CAL/DOL
5
10
44
62
88
124
176
249
352
498
PARTICLE SIZE, micrometres

TABLE 5.12 Cyclone Performance using Plitt's Model of Cyclone Classification. Tonnage: 154.2 mtph

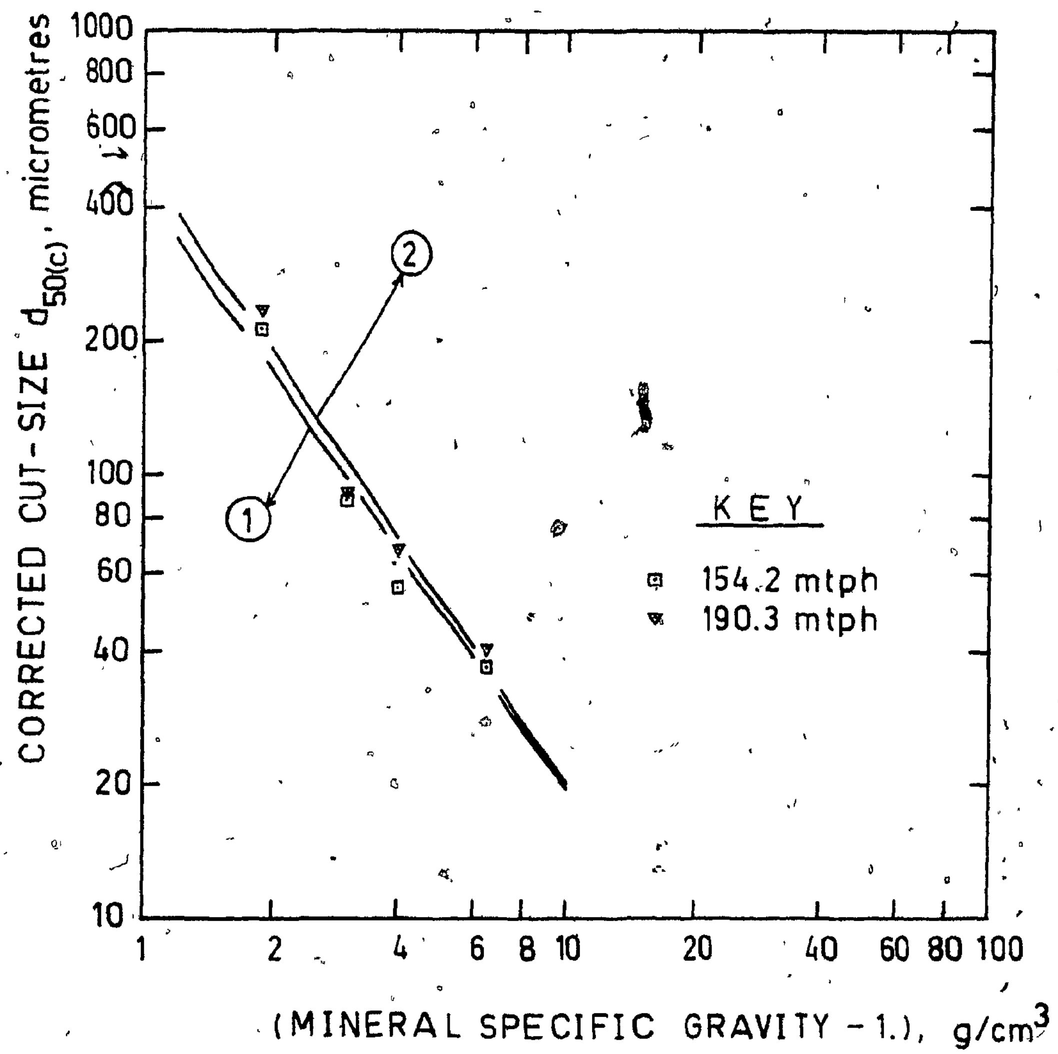
size d, μm (geometrical mean)	Classification Index, $Y'_{m,i}$			
	PbS	ZnS	FeS_2	Cal/Dol
704	0.9812	0.9845	0.9844	0.9645
498	0.9103	0.9807	0.8615	0.9585
352	1.0000	1.0000	0.9814	0.8490
249	1.0000	0.9834	0.9373	0.6900
176	0.9670	0.9525	0.8648	0.4038
124	0.9655	0.7404	0.9229	0.1760
88	0.9715	0.5348	0.7684	0.1574
62	0.8959	0.2347	0.5191	0.0000
44	0.6438	0.1733	0.2095	0.0676
a_m	0.3951	0.2886	0.3545	0.2306
$d_{50(C)m}$, μm	36.98	88.84	65.97	201.16
n_m	2.288	2.004	2.272	2.282

TABLE 5.13 Cyclone Performance using Plitt's Model of Cyclone Classification. Tonnage: 190.3 mtph

size d, μm, (geometrical mean)	Classification Index, $Y'_{m,i}$			
	PbS	ZnS	FeS_2	Cal/Dol
704	1.0000	1.0000	0.9554	0.9596
498	0.9920	0.9938	0.9265	0.9723
352	0.9689	0.9631	0.9685	0.8566
249	0.9965	0.9726	0.9649	0.5480
176	0.9902	0.8997	0.9492	0.2732
124	0.9710	0.7897	0.8619	0.0627
88	0.9628	0.4491	0.7307	0.0003
62	0.7882	0.0933	0.3982	0.0000
44	0.5689	0.0918	0.2279	(-0.2674)
a_m	0.6241	0.4665	0.6951	0.2819
$d_{50(C)m}$, μm	40.62	92.86	68.25	236.44
n_m	1.992	2.803	2.344	2.627

FIGURE 5.32

General cyclone model. Corrected cut-size $d_{50(C)m}$ vs. mineral specific gravity. Regression lines 1 for 154.2 and 2 for 190.3 mtph plant tonnages (log-log scale).



1000
800
600
400
200
100
80
60
40
20
10
CORRECTED CUT-SIZE d50(c), micrometres
1
2
4
6
8
10
20
40
60
80
100
(MINERAL SPECIFIC GRAVITY - 1.), g/cm3
KEY
154.2 mtph
190.3 mtph

Line 1 (154.2 mtph)

$$\ln \{d_{50(C)m}\} = -1.332 \ln \{\rho_m - 1\} + 6.053 \quad (5.1)$$

Line 2 (190.3 mtph)

$$\ln \{d_{50(C)m}\} = -1.384 \ln \{\rho_m - 1\} + 6.202 \quad (5.2)$$

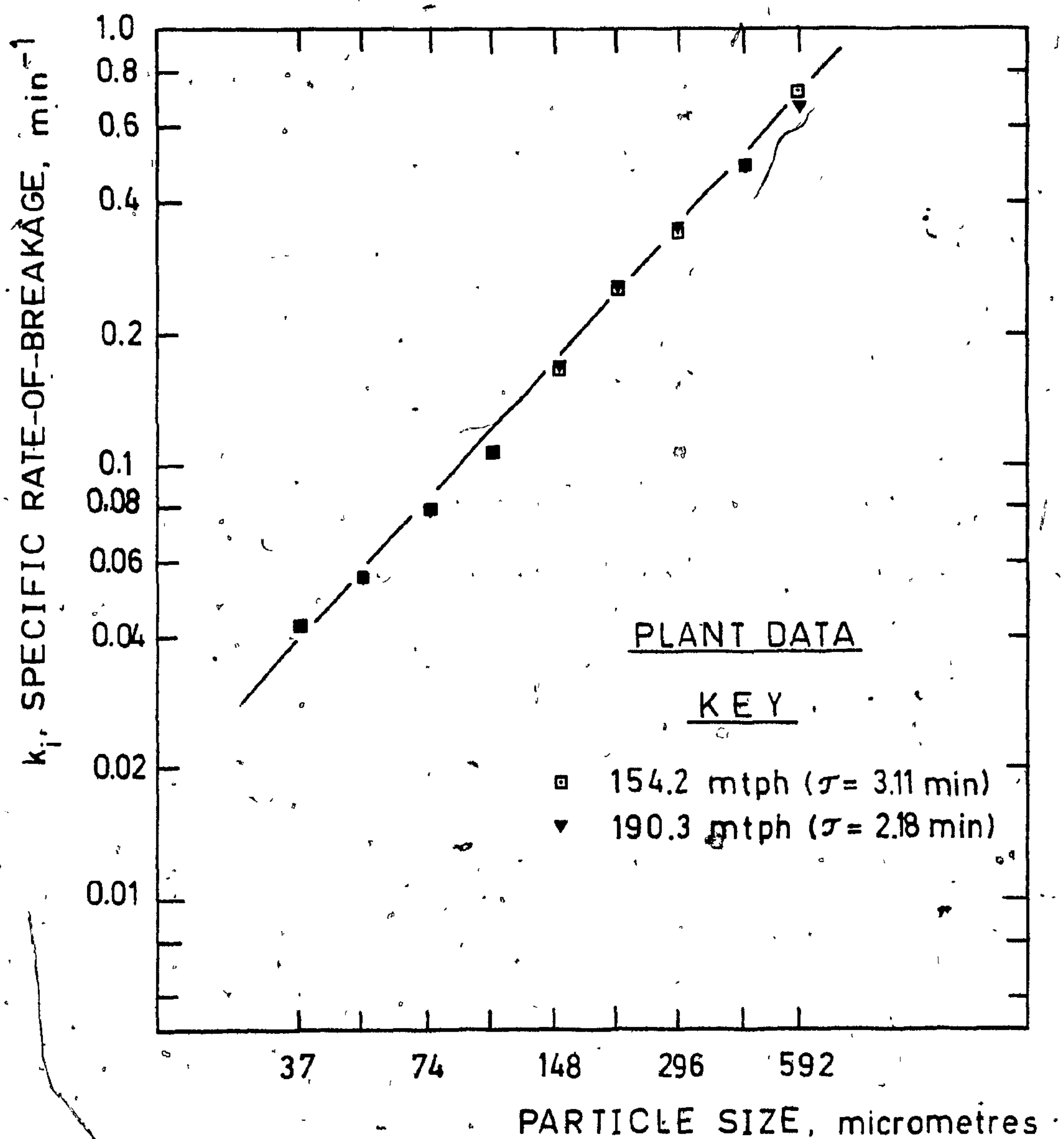
where ρ_ℓ has taken the value 1 (water). The analysis just described has made use of the assumption that a_m in Equation (2.2.4) is the -400# of minerals short-circuited to the underflow. Such an assumption is not necessarily correct for all the mineral species, especially for the denser ones, galena and pyrite (see Figures 5.28 and 5.30). Nevertheless, in the absence of information on the sub-sieve fractions, the assumption yields reasonable results. An alternate procedure is to estimate a_m for which true short-circuiting is physically real. The task is beyond the scope of this work.

5.2.3 Plant-Derived First Order Rate-of-Breakage (Overall)

Figure 5.33 shows the plots of k_i, cumulative-basis specific rate-of-breakage vs. d, particle size, for the 154.2 and 190.3 mtph cases. k_i was back-calculated with the use of the adjusted overall size assays of CUF (cyclone underflow or ball mill feed) and BMD (ball mill discharge), the volumetric ball mill holdup (Appendix III, Section III.3), and the known pulp dilution of CUF stream. The equation used was Equation (2.1.6) in the following form:

FIGURE 5.33

Plant derived overall first-order rate-of-breakage vs. particle size. Plant operation fresh throughputs at 154.2 and 190.3 mtph (log-log scale).



1.0
0.8
0.6
0.4
0.2
0.1
0.08
0.06
0.04
0.02
0.01
k_i, SPECIFIC RATE-OF-BREAKAGE, min^{-1}
37
74
148
296
592
PARTICLE SIZE, micrometres
PLANT DATA
KEY
154.2 mtph (τ = 3.11 min)
190.3 mtph (τ = 2.18 min)

$$k_i = -\ln\{C_i(\tau)/C_i(0)\}/\tau \qquad (5.3).$$

where: τ is mean residence time, min $(=\frac{BMH}{VF})$ (Equation (2.1.14)

$C_i(0)$ is cumulative size assay coarser (Pct) of cyclone underflow (adjusted)

$C_i(\tau)$ is cumulative size assay coarser (Pct) of ball mill discharge (adjusted)

BMH is volumetric ball mill holdup (m^3)

VF is the volumetric flow rate of pulp in ball mill feed (m^3/min).

VF at 154.2 and 190.3 mtph was calculated using the specific gravity of the solids entering the ball mill (using the adjusted data and the known density of the mineral species composing the ore) and the measured pulp dilution. In summary, the calculated mean residence times are:

$$\tau_{154.2 \text{ mtph}} = 3.11 \text{ min}$$

$$\tau_{190.3 \text{ mtph}} = 2.18 \text{ min}$$

Regression analysis on the data gives the following:

<u>Case 1, 154.2 mtph</u>

$$k_{i,1} = 8.92 \times 10^{-4} \cdot d^{1.043}$$

Case 2, 190.3 mtph

$$k_{i,2} = 9.44 \times 10^{-4} \cdot d^{1.042}$$

Cases 1 and 2

$$k_{i,1-2} = 9.18 \times 10^{-4} \cdot d^{1.043}$$

where: k_i is the first order rate-of-breakage (min^{-1}).

d is the screen size opening (μm)

Table 5.14 shows the plant-derived first order rate-of-breakage and for comparison the p and first order rates-of-breakage drawn from the batch laboratory experiments on the CUF material. The similarity is striking.

5.3 Simulation

5.3.1 Ball Mill Only

The ball mill was simulated mineral-by-mineral using the known mean residence time at 154.2 mtph (τ = 3.11 min). The p-order model of grinding was utilized along with the lab-derived parameters from the CUF experiments. The mill feed mineral distribution, in cumulative coarser form, $C_{m,i}(0)$ was calculated from the adjusted results reported in Appendix IV. The equation used to determine the size distribution of the product, $C_{m,i}(\tau)$ was:

TABLE 5.14 First-Order Rate-of-Breakage $k_{i,plant}$ of Overall Mineral, Back-Calculated using Plant Data Compared with Lab-Derived p-Order Instantaneous Rate-of-Breakage $k_{i,lab-p}$ and Lab-Derived 1st-Order Rate-of-Breakage $k_{i,lab-1st}$.

Particle Size µm	154.2 mtph; τ = 3.11 min			190.3 mtph; τ = 2.18 min		
	$k_{i,plant}$	$k_{i,lab-p}$	$k_{i,lab-1st}$	$k_{i,plant}$	$k_{i,lab-p}$	$k_{i,lab-1st}$
600	0.7124	0.5563	0.4247	0.6753	0.6006	0.4247
425	0.4981	0.5348	0.4897	0.4990	0.5486	0.4897
300	0.3400	0.4181	0.4614	0.3481	0.4063	0.4614
212	0.2511	0.3049	0.3412	0.2593	0.2955	0.3412
150	0.1671	0.1898	0.2082	0.1716	0.1850	0.2082
106	0.1072	0.1158	0.1233	0.1093	0.1138	0.1233
75	0.0790	0.0764	0.0788	0.0782	0.0756	0.0788
53	0.0549	0.0486	0.0506	0.0549	0.0478	0.0506
38	0.0426	0.0372	0.0385	0.0416	0.0366	0.0385

$$C_{m,i}(\tau) = C_{m,i}(0) \exp \{- Fg_m b_{m,i} \tau^{p_{m,i}}\} \qquad (2.1.14)$$

Fg_m for PbS was taken as 0.7; for the other minerals Fg_m was taken at value 1 (see later). Table 5.15 shows the simulation results for PbS. Figures 5.34 and 5.35 show the mineral frequency distributions of PbS, ZnS, FeS_2 and calcite-dolomite, as cumulative WT. PCT. finer vs. particle size for the CUF and RMD streams. Clearly, the simulation of BMD using the laboratory derived kinetics is quite successful. Only in the case of PbS was the plant-fitted Fg_m parameter required. As a note of interest, observe that the extent of size reduction decreases in the order calcite/dolomite, sphalerite, pyrite, galena.

5.3.2 Actual Circuit, Mineral-by-Mineral

The actual circuit was simulated at the two throughputs of 154.2 and 190.3 mtph and with two different cyclone models. In all cases, the grinding operation was simulated using the mineral-by-mineral p-order model. The computer programs utilized were those described in Section 4.1 and 4.2. The simulation results are displayed in Appendix V, Sections V.1.1, V.1.2, V.2.1 and V.2.2. Some of the most relevant results are summarized in Table 5.16. Model 1, employing the cyclone matrix model, in general, shows the best simulation. This is equivalent to saying that the ball mill simulation is quite accurate as the cyclone model is 'perfect'. Correspondence between measured and simulated data when using the combined cyclone model is not quite so good. This is a measure of the error introduced when attempting to model the cyclone to incorporate design and operating variables.

TABLE 5.15 Simulated Size Reduction of PbS in the Ball Mill. Results in Percent by Weight of PbS Frequency Distribution.

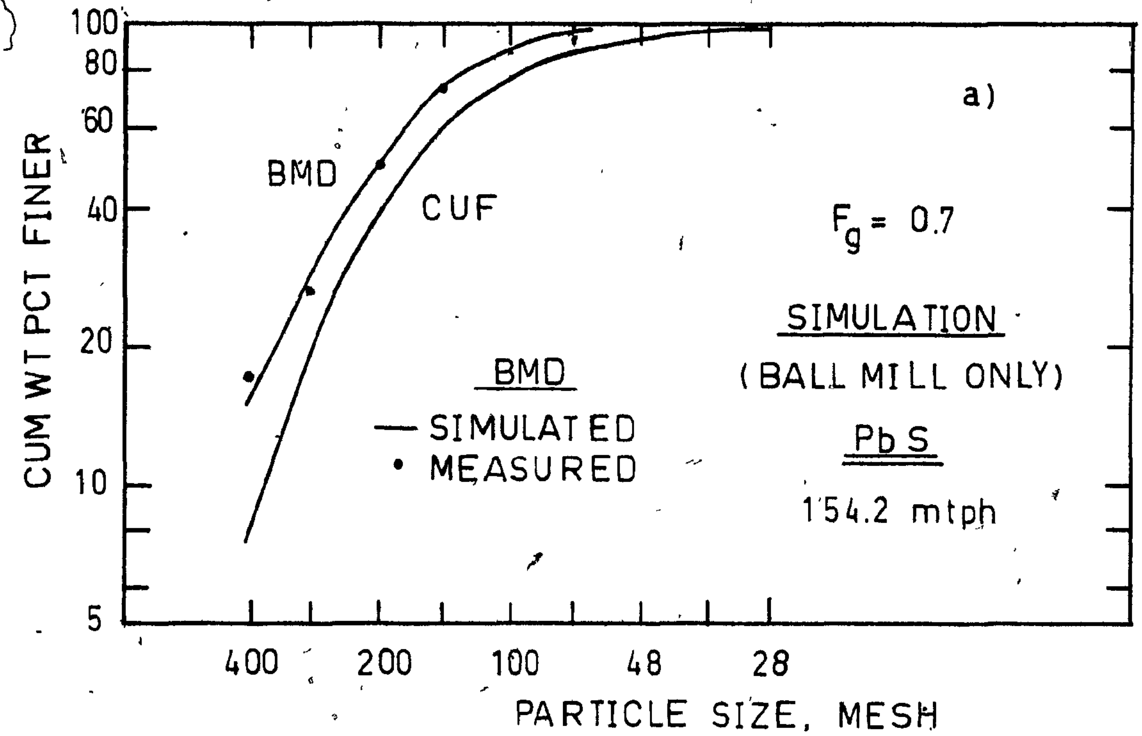
	Ball Mill Feed	Ball Mill Discharge	
Mesh No.	Measured	Simulated	Measured
28	2.95	0.66	0.01
35	1.27	0.39	0.32
48	3.22	1.02	1.54
65	4.93	2.61	4.06
100	9.73	7.23	7.60
150	14.25	13.29	13.13
200	24.21	23.03	23.47
270	23.19	24.81	23.35
400	8.08	9.95	9.39
-400	8.14	17.01	17.19

DATA USED:

ball mill holdup,	BMH	=	8.366 m^3 (Appendix III, Section III.3)
fresh feed tonnage,	SOL1	=	154.2 mtph
overall circ. load,	CLOV	=	1.63 (Appendix IV, Section IV.2.1)
pulp dilution,	PCTS4	=	73.56% by weight
Sp. Gr. of mill feed ore,	ρ_{OV}	=	3.54 tonne/m^3
PbS grinding factor,	Fg_{PbS}	=	0.70

FIGURE 5.34

Simulation of ball mill only, using lab derived grinding parameters. Tonnage: 154.2 mtph.
a) PbS; b) ZnS.


100
80
60
40
20
10
5
CUM WT PCT FINER
400
200
100
48
28
PARTICLE SIZE, MESH
a)
BMD
CUF
F_g = 0.7
SIMULATION
(BALL MILL ONLY)
BMD
— SIMULATED
• MEASURED
PbS
154.2 mtph

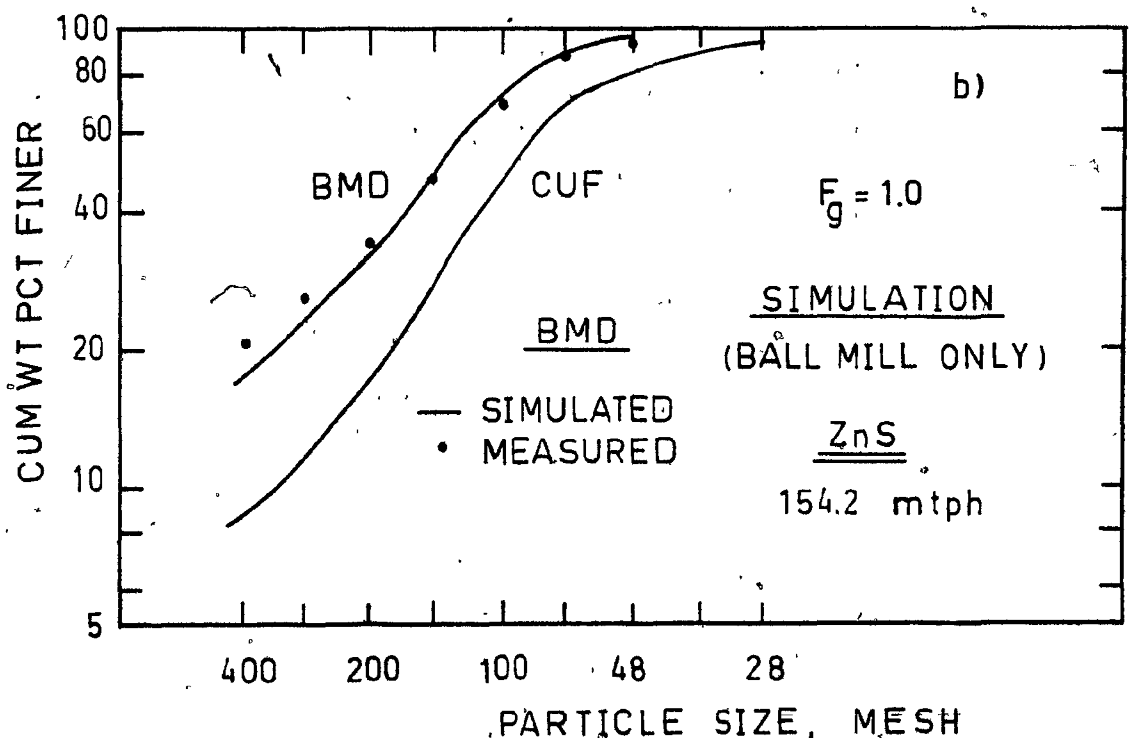
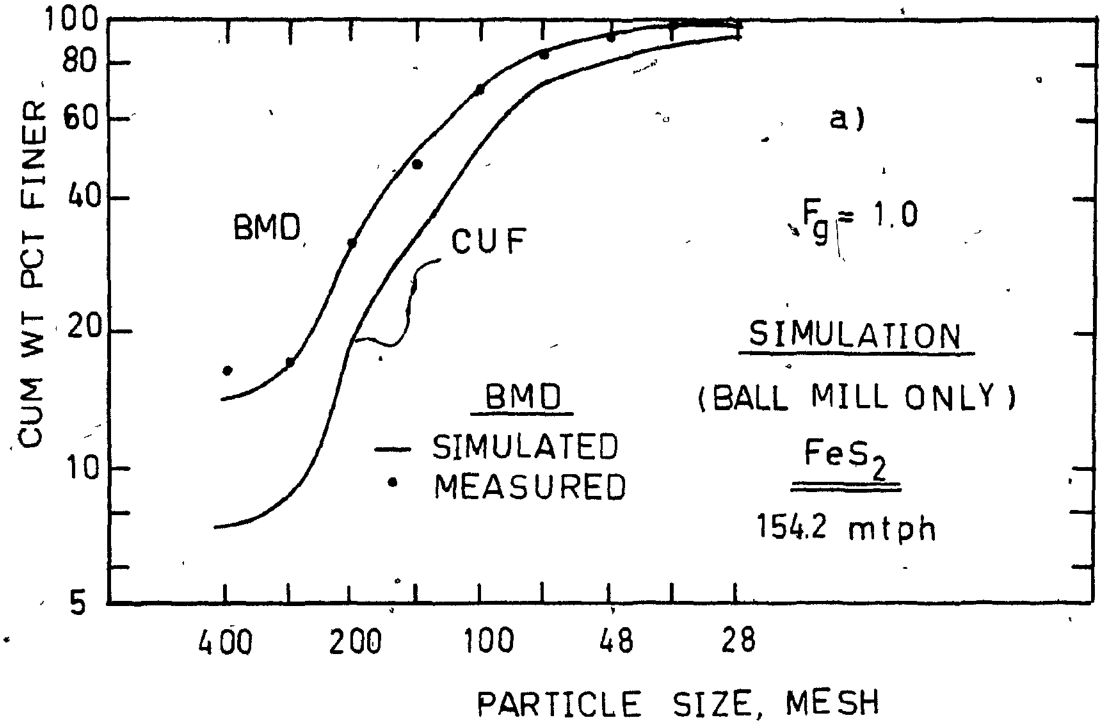

100
80
60
40
20
10
5
CUM WT PCT FINER
400
200
100
48
28
PARTICLE SIZE, MESH
b)
BMD
CUF
F_g = 1.0
SIMULATION
(BALL MILL ONLY)
BMD
— SIMULATED
• MEASURED
ZnS
154.2 mtph

FIGURE 5.35

Simulation of ball mill only, using lab derived grinding parameters. Tonnage: 154.2 mtph. a) FeS_2; b) cal/dol.


100
80
60
40
20
10
5
CUM WT PCT FINER
BMD
CUF
a)
Fg = 1.0
SIMULATION
(BALL MILL ONLY)
BMD
— SIMULATED
• MEASURED
FeS2
154.2 mtph
400
200
100
48
28
PARTICLE SIZE, MESH

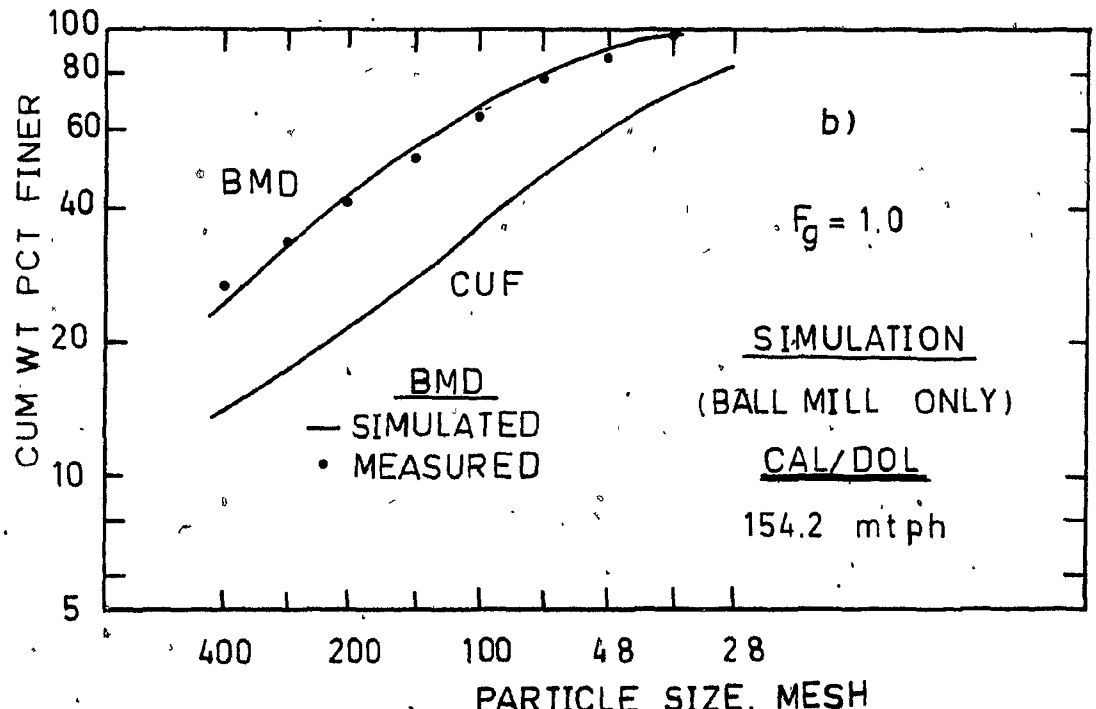

100
80
60
40
20
10
5
CUM WT PCT FINER
BMD
CUF
b)
Fg = 1.0
SIMULATION
(BALL MILL ONLY)
BMD
— SIMULATED
• MEASURED
CAL/DOL
154.2 mtph
400
200
100
48
28
PARTICLE SIZE, MESH

TABLE 5.16 Circuit Simulation using Lab Grind Kinetics (p-Order) and Plant-Fitted Fg_m Grinding Factors

Quantity	154.2 mtph			190.3 mtph		
		Simulation*			Simulation	
	Measured	Model 1**	Model 2***	Measured	Model 1	Model 2
Circulating load, PCT						
PbS	581	536	552	1022	830	728
ZnS	237	221	207	~~376~~	364	280
FeS_2	380	379	401	854	814	566
Cal/Dol	103	98	116	120	~~124~~	135
Overall	163	157	173	200	196	183
CUM PCT -200# COF						
PbS	94.16	94.76	99.49	93.95	95.12	100.00
ZnS	75.03	72.41	67.48	72.82	67.93	67.93
FeS_2	77.16	75.11	78.14	77.05	77.06	81.99
Cal/Dol	56.87	56.76	58.04	47.01	45.32	52.36
Overall	62.90	61.42	62.45	52.80	49.70	56.07
Mean Res. Time τ(min)	3.11	3.26	3.10	2.18	1.88	2.43
Sp. Gr. of CUF (g/cm^3)	3.54	3.63	3.56	3.49	3.50	3.34

* p-order model, perfect plug flow mill
$Fg_{PbS} = 0.70$; $Fg_{ZnS} = Fg_{FeS_2} = Fg_{Cal/Dol} = 1.0$

** Model 1 uses cyclone matrix model
*** Model 2 uses combined cyclone model

Figures 5.36-39 show the overall, PbS, ZnS and FeS_2 size-frequency distribution for the COF and BMD for both tonnages. The solid lines are the simulated results and the symbols represent the adjusted measured frequency distribution. Also shown on the graphs are the grinding factors Fg_m; 0.7 for PbS and 1.0 for the other mineral components. These factors were identified by matching the measured mineral circulating load. Observe that simulation of the circuit for the high tonnage case, 190.3 mtph, yields simulation results as good as, if not better, than the 154.2 mtph case from which material the grind kinetics parameters were obtained.

The mineral-by-mineral instantaneous rates-of-breakage calculated at steady state conditions (Sections V.5.1 and V.5.2) are plotted in Figure 5.40. Compared with the laboratory derived data in Figure 5.29 the principle difference is a reduced PbS rate-of-breakage.

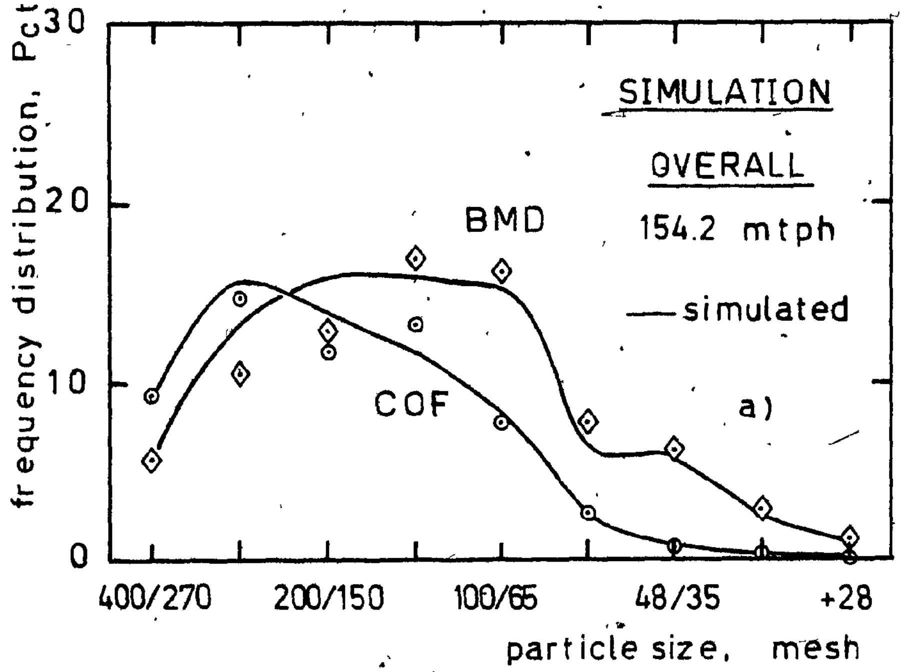
5.3.3 Proposed Circuit

The proposed circuit performances at 154.2 and 190.3 mtph were predicted by means of the computer program described in Section 4.3. The program is shown in Appendix V, Section V.3, with the input data and results shown in Sections V.3.1 and V.3.2. Table 5.17 summarizes some relevant results of these predictions.

The simulations used the p-order grinding and $Y_{m,i}$ classification matrix models. Simulated actual circuit data is included for comparison. The circulating load of galena decreases considerably, while for the other minerals it is much the same. The size distribution of minerals in the COF appears to be the same, but the real circuit product now is

FIGURE 5.36

Simulation of the actual grinding circuit, overall. Streams: cyclone overflow (COF) and ball mill discharge (BMD). Mass frequency distribution vs. particle size. a) 154.2 mtph; b) 190.3 mtph.


frequency distribution, Pct.
SIMULATION
OVERALL
154.2 mtph
— simulated
BMD
COF
a)
400/270
200/150
100/65
48/35
+28
particle size, mesh

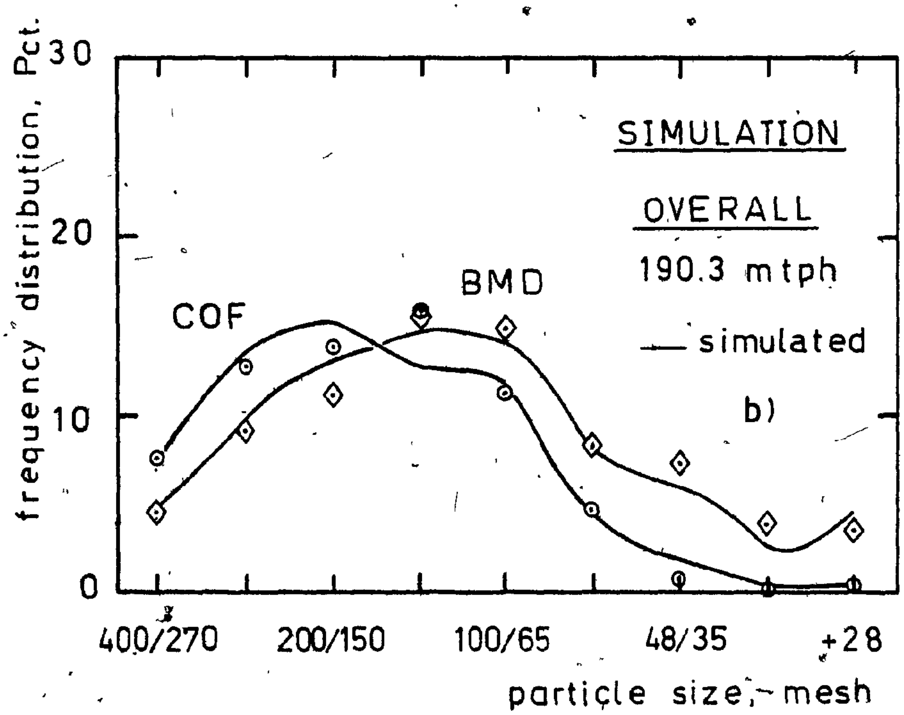
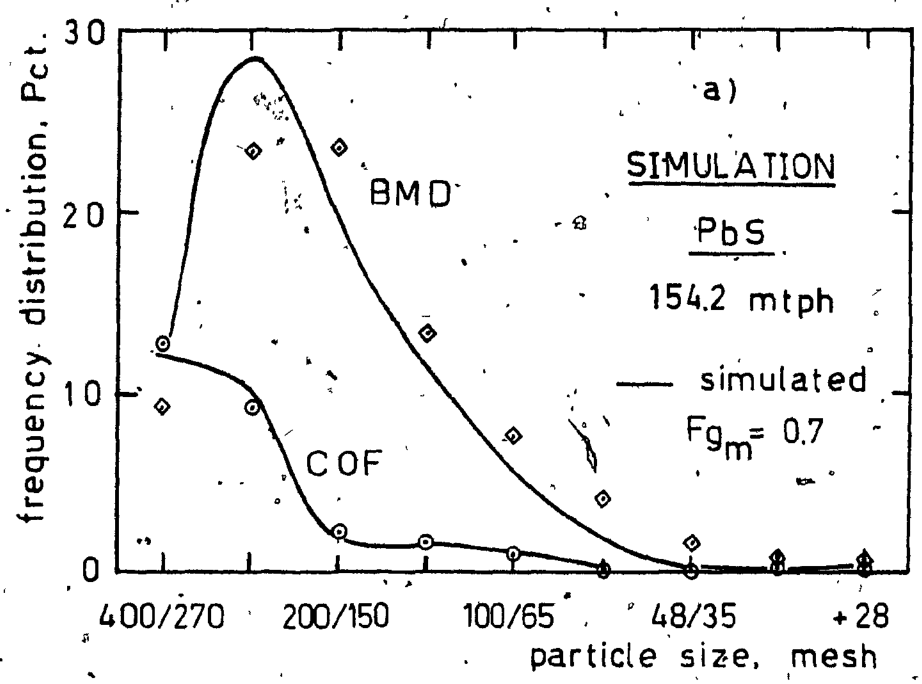
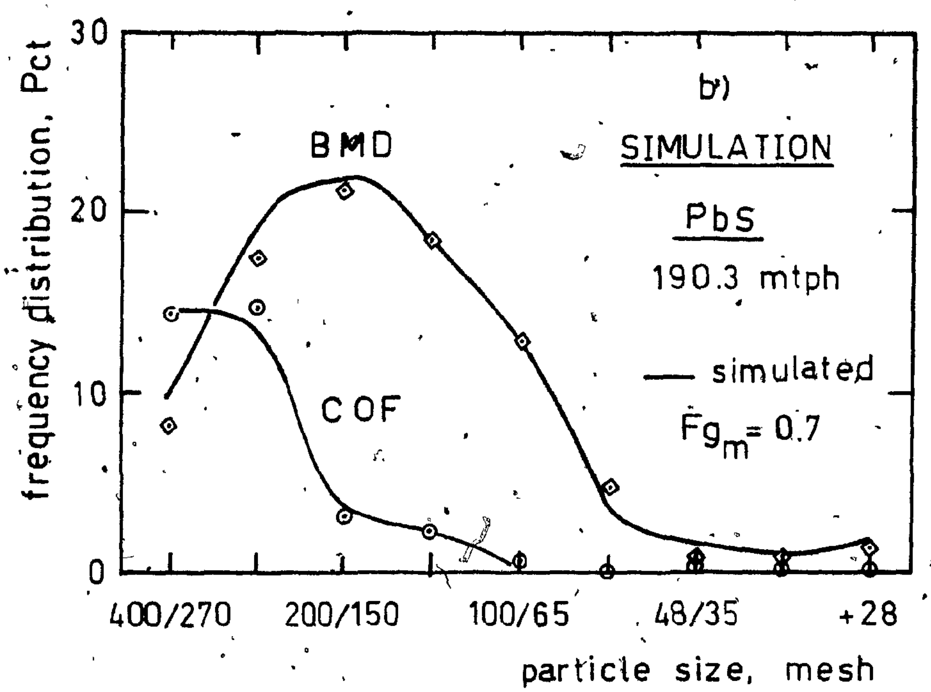

frequency distribution, Pct.
SIMULATION
OVERALL
190.3 mtph
— simulated
BMD
COF
b)
400/270
200/150
100/65
48/35
+28
particle size, mesh

FIGURE 5.37

Simulation of the actual grinding circuit. Mineral: galena (PbS). Streams: cyclone overflow (COF) and ball mill discharge (BMD). Mass frequency distribution vs. particle size. a) 154.2 mtph; b) 190.3 mtph.



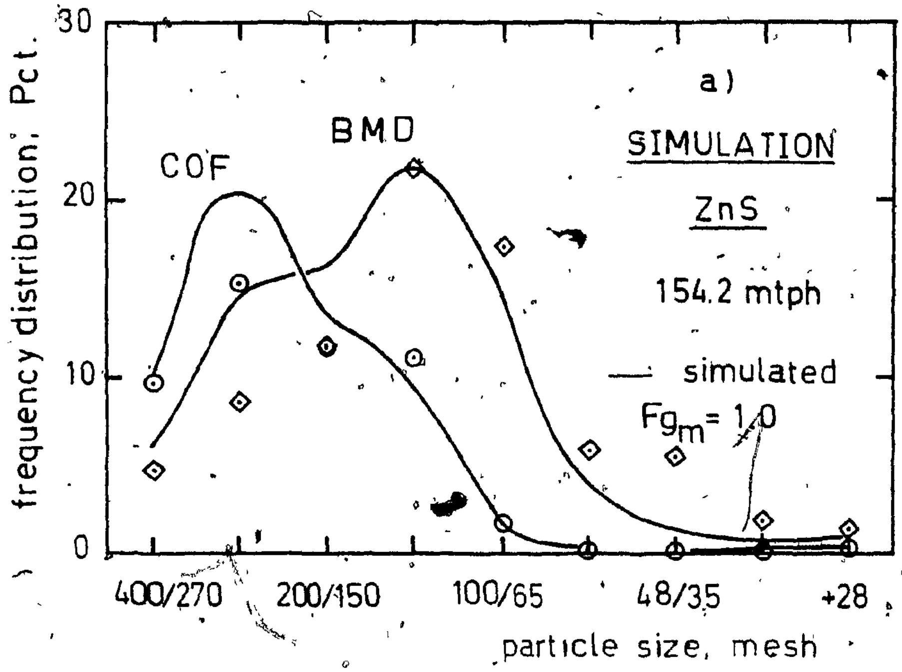
30
20
10
0
frequency distribution, Pct.
a)
SIMULATION
PbS
154.2 mtph
— simulated
Fg_m= 0.7
BMD
COF
400/270
200/150
100/65
48/35
+28
particle size, mesh



30
20
10
0
frequency distribution, Pct
b)
SIMULATION
PbS
190.3 mtph
— simulated
Fg_m= 0.7
BMD
COF
400/270
200/150
100/65
48/35
+28
particle size, mesh

FIGURE 5.38

Simulation of the actual grinding circuit. Mineral: sphalerite (ZnS). Streams: cyclone overflow (COF) and ball mill discharge (BMD). Mass frequency distribution vs. particle size. a) 154.2 mtph; b) 190.3 mtph.


30
20
10
0
frequency distribution, Pct.
a)
SIMULATION
ZnS
154.2 mtph
— simulated
Fg_m = 1.0
BMD
COF
400/270
200/150
100/65
48/35
+28
particle size, mesh

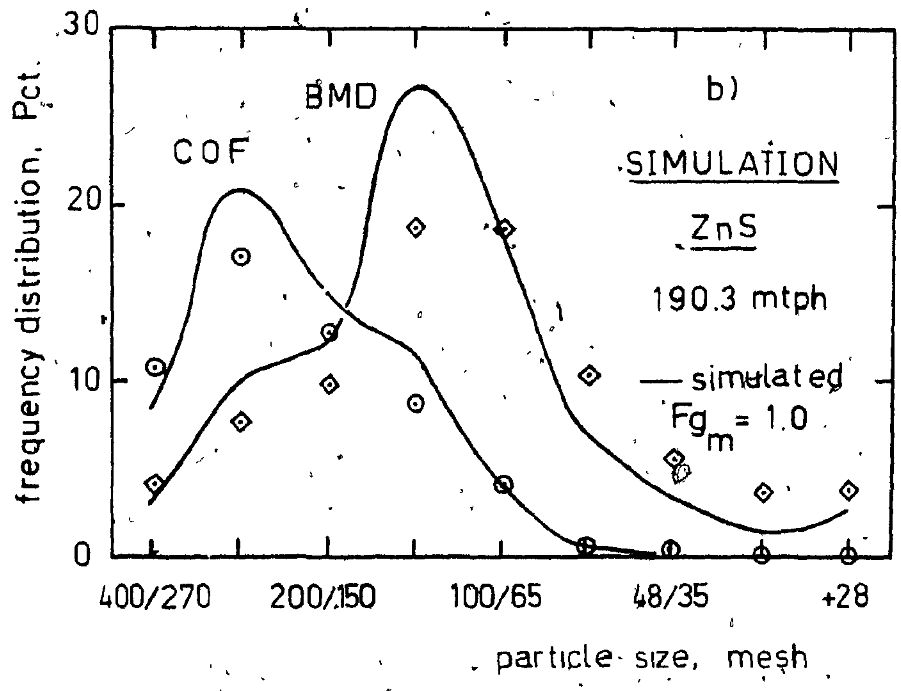
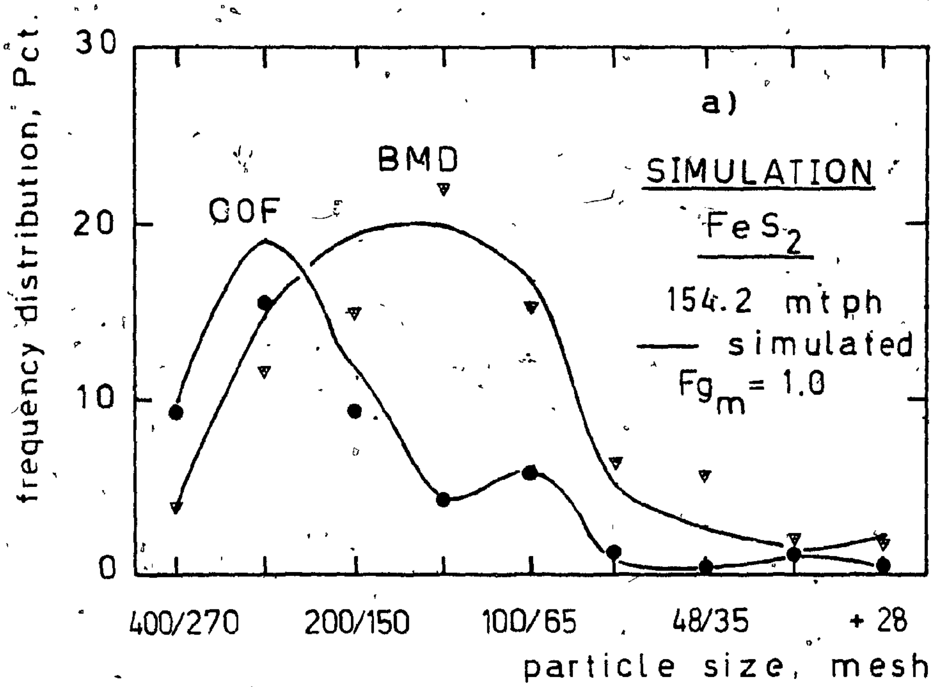
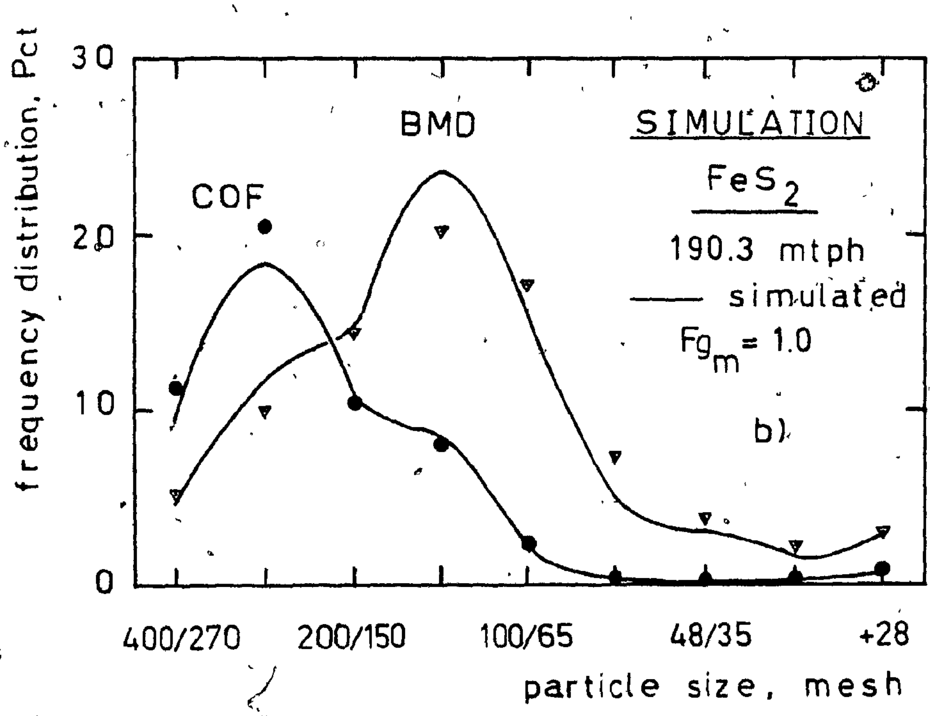

30
20
10
0
frequency distribution, Pct.
b)
SIMULATION
ZnS
190.3 mtph
— simulated
Fg_m = 1.0
BMD
COF
400/270
200/150
100/65
48/35
+28
particle size, mesh

FIGURE 5.39

Simulation of the actual grinding circuit. Mineral: pyrite (FeS_2). Streams: cyclone overflow (COF) and ball mill discharge (BMD). Mass frequency distribution vs. particle size. a) 154.2 mtph; b) 190.3 mtph.



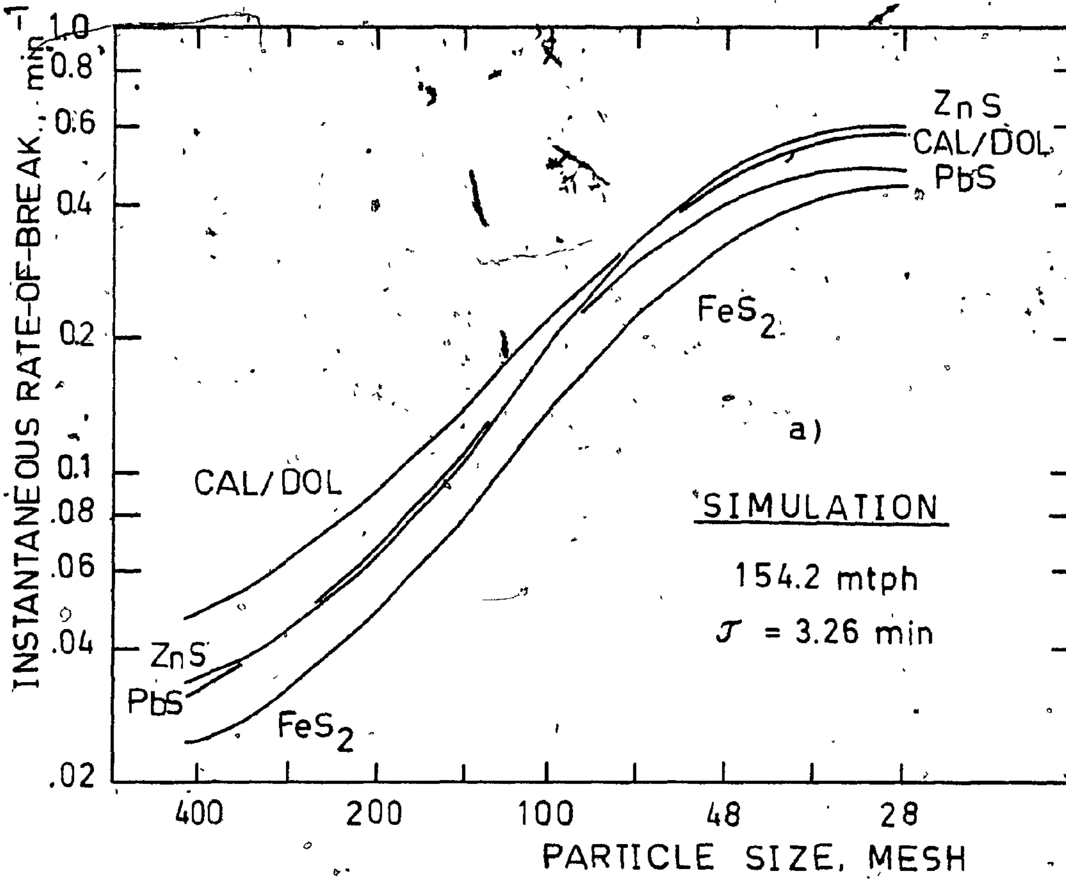
30
20
10
0
frequency distribution, Pct
a)
COF
BMD
SIMULATION
FeS_2
154.2 mtph
simulated
Fg_m = 1.0
400/270
200/150
100/65
48/35
+ 28
particle size, mesh



30
20
10
0
frequency distribution, Pct
BMD
COF
SIMULATION
FeS_2
190.3 mtph
simulated
Fg_m = 1.0
b)
400/270
200/150
100/65
48/35
+28
particle size, mesh

FIGURE 5.40

Actual circuit. Simulated instantaneous-rates-of-breakage vs. particle size. Minerals: galena, sphalerite, pyrite and calcite/dolomite. a) 154.2 mtph; b) 190.3 mtph.


INSTANTANEOUS RATE-OF-BREAK., min⁻¹
1.0
0.8
0.6
0.4
0.2
0.1
.08
.06
.04
.02
ZnS
CAL/DOL
PbS
FeS2
CAL/DOL
ZnS
PbS
FeS2
a)
SIMULATION
154.2 mtph
τ = 3.26 min
400
200
100
48
28
PARTICLE SIZE, MESH

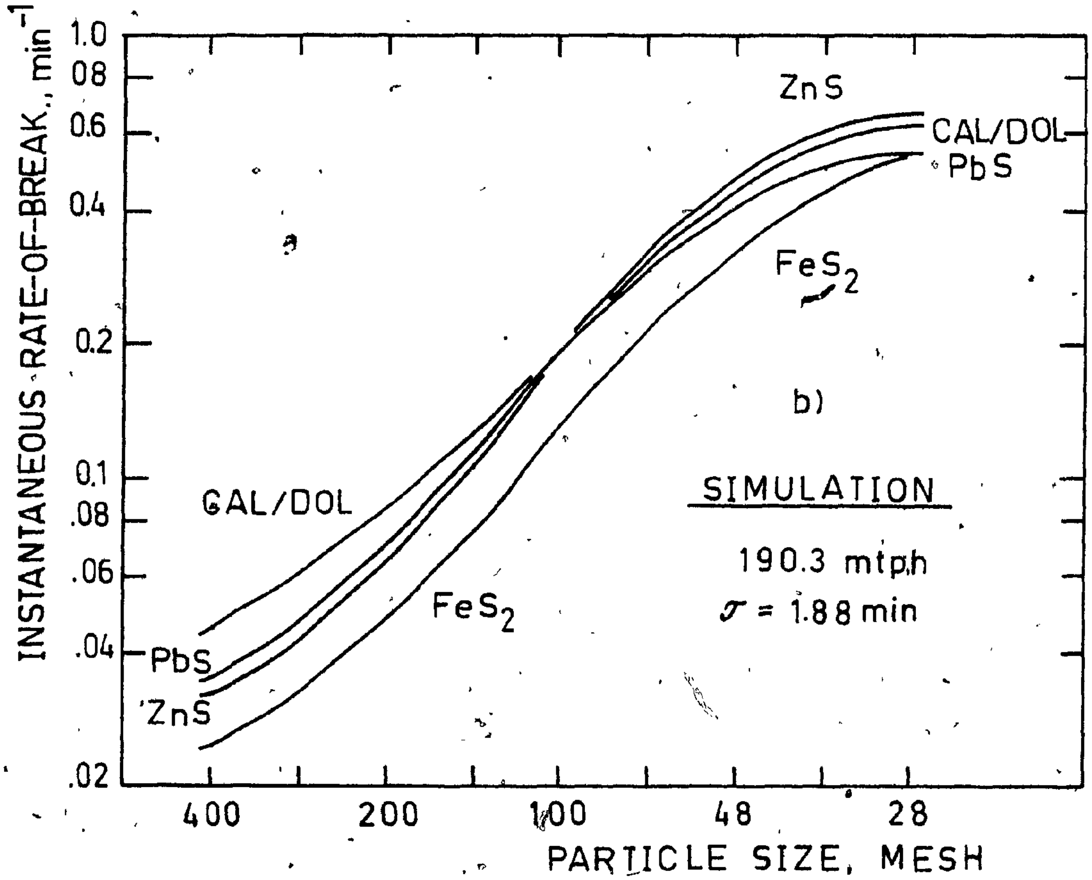

INSTANTANEOUS RATE-OF-BREAK., min⁻¹
1.0
0.8
0.6
0.4
0.2
0.1
.08
.06
.04
.02
ZnS
CAL/DOL
PbS
FeS2
b)
CAL/DOL
SIMULATION
190.3 mtph
τ = 1.88 min
PbS
ZnS
FeS2
400
200
100
48
28
PARTICLE SIZE, MESH

TABLE 5.17 Prediction of Proposed Grinding Circuit Performance. Comparison is made with the Simulation Results of the Actual Circuit.*

ITEM	154.2 mtph		190.3 mtph	
	Actual	Proposed	Actual	Proposed
circulating load, %				
PbS	536	139	830	173
ZnS	221	205	364	320
FeS_2	379	387	814	802
Cal/Dol	98	100	124	125
Overall	157	150	196	182
CUM PCT -200# COF				
PbS	94.76	92.75	95.12	95.00
ZnS	72.91	72.19	67.93	67.81
FeS_2	75.11	73.87	77.06	75.46
Cal/Dol	56.76	56.13	45.32	44.97
Overall	61.42	60.04	49.70	48.21
CUM PCT -200# COF+CONC				
PbS		54.59		46.77
ZnS		68.71		63.01
FeS_2		74.08		76.08
Cal/Dol		56.20		45.08
Overall		59.78		48.23
PbS recovery, % flot. cell		54.		48.
PbS recovery, % across circuit		76.		84.

* Simulation based on model 1 in Table 5.15.

stream 8, the COF + CONC. Since a considerable portion of the PbS leaves in the CONC, and is quite coarse, the PbS grind product is considerably coarser; from 95% -200 mesh at both tonnages to 55% and 47% -200 mesh at 154.2 and 190.3 mtph, respectively. The product size of the other minerals is hardly affected in comparison, with the ZnS coarsening by about 4% (absolute) on -200 mesh, showing the greatest change.

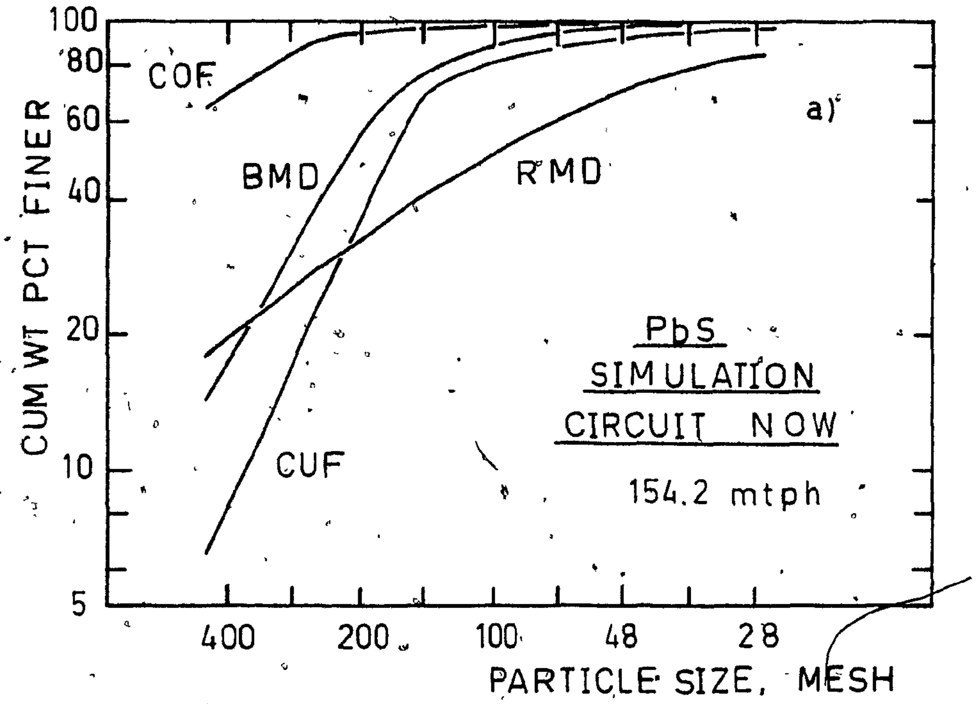
A notable result is the comparison of PbS recovery across the cell and across the circuit. Across the circuit, recovery is between 22% higher (at 154.2 mtph) and 36% higher (at 190.3 mtph).

The PbS behaviour in both circuit configurations, the actual and the proposed, is shown in Figures 5.41 and 5.42, for the 154.2 and 190.3 mtph cases, respectively. The plots are drawn on the Schuhmann-Gaudin-Gates chart (log-log scale). The upper sections correspond to the simulation of the actual circuit where the solid lines RMD, CUF, COF and BMD were plotted using the simulation results of Sections V.1.1 and V.1.2.

The dashed lines in the lower sections are the predicted COF and flotation concentrate (GONC) PbS size distribution. A solid line marked COF + CONC is the stream 8 shown in Figure 1.2. This illustrates the coarsening of the PbS grind product. Since no regrinding is performed at Pine Point, the COF (actual) and COF + CONC (proposed) represent the approximate size distribution of the final lead concentrate product. The desired coarsening of this product is clearly demonstrated.

FIGURE 5.41

Simulation results. Cumulative weight percent finer vs. particle size. Mineral: galena (PbS). Overall fresh throughput: 154.2 mtph. a) actual circuit; b) proposed circuit.


CUM WT PCT FINER
100
80
60
40
20
10
5
COF
BMD
RMD
CUF
a)
PbS
SIMULATION
CIRCUIT NOW
154.2 mtph
400
200
100
48
28
PARTICLE SIZE, MESH

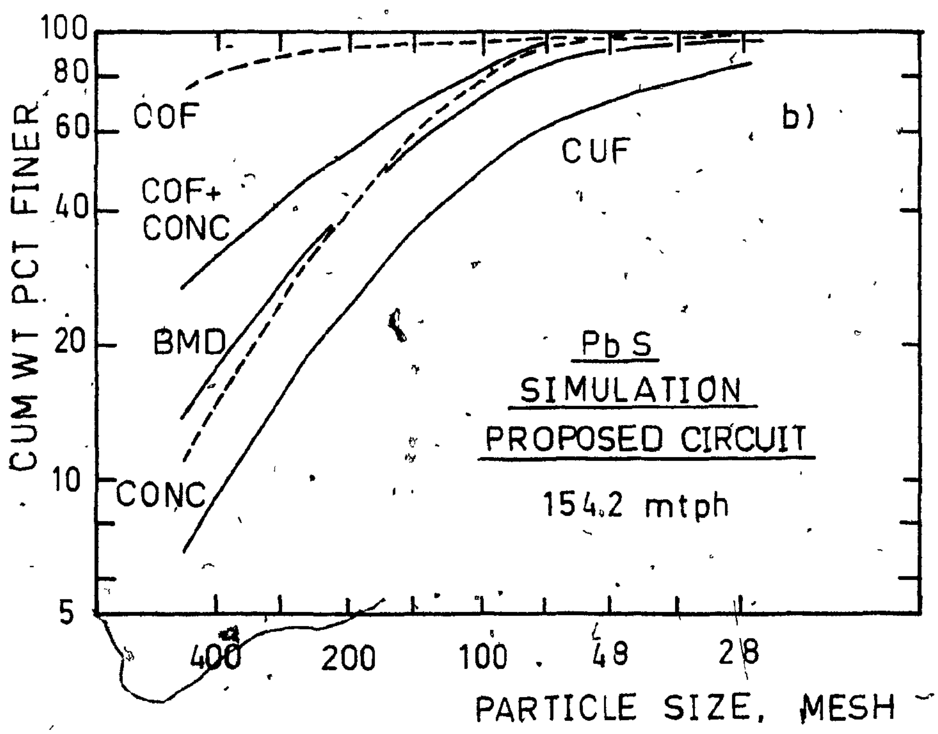
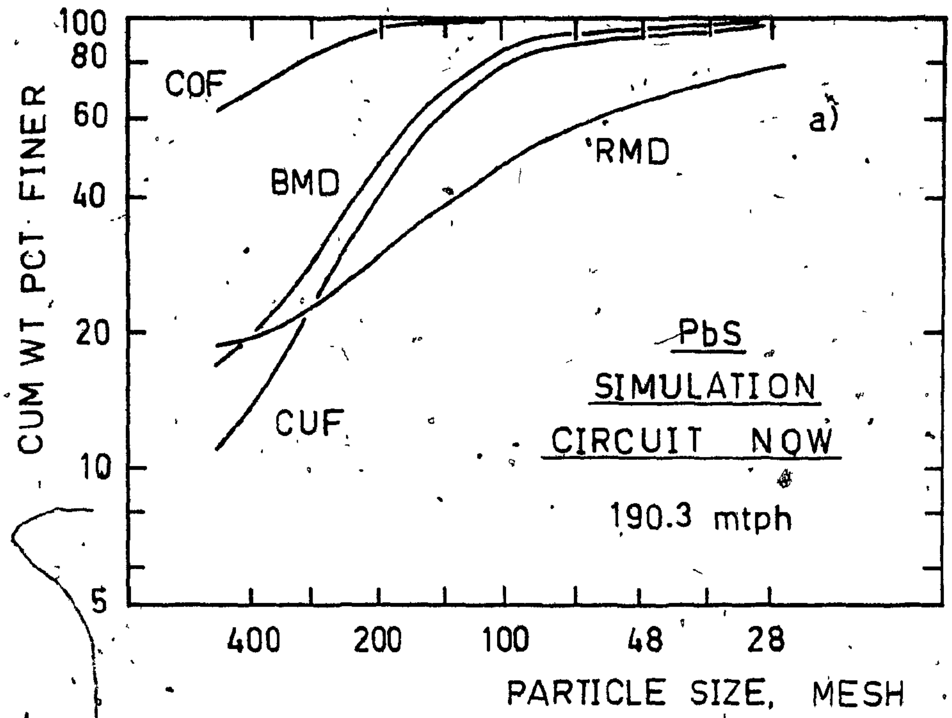
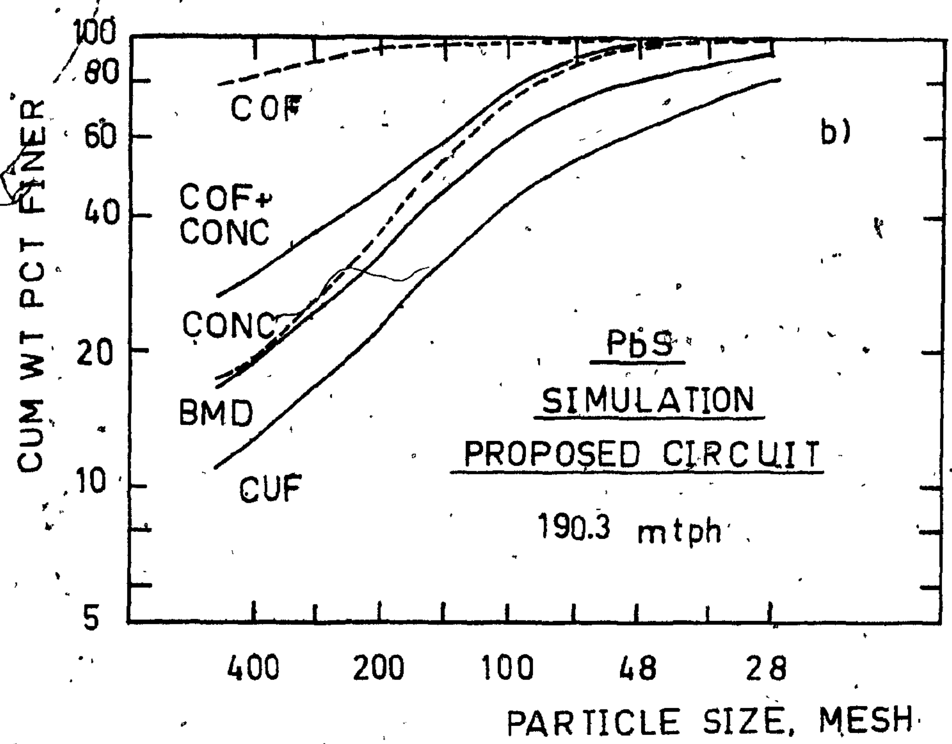

CUM WT PCT FINER
100
80
60
40
20
10
5
COF
COF+
CONC
BMD
CONC
CUF
b)
Pb S
SIMULATION
PROPOSED CIRCUIT
154.2 mtph
400
200
100
48
28
PARTICLE SIZE, MESH

FIGURE 5.42

Simulation results. Cumulative weight percent finer vs. particle size. Mineral: galena (PbS). Overall fresh throughput: 190.3 mtph. a) actual circuit; b) proposed circuit.


CUM WT PCT FINER
100
80
60
40
20
10
5
COF
BMD
RMD
CUF
a)
PbS
SIMULATION
CIRCUIT NOW
190.3 mtph
400
200
100
48
28
PARTICLE SIZE, MESH


CUM WT PCT FINER
100
80
60
40
20
10
5
COF
COF+
CONC
CONC
BMD
CUF
b)
PbS
SIMULATION
PROPOSED CIRCUIT
190.3 mtph
400
200
100
48
28
PARTICLE SIZE, MESH

5.3.4 Plug Flow vs. Tanks-in-Series

Taking the p-order model with $Fg_m = 1$ and the Y_i matrix model, two simulations were performed. In the first, the mill was assumed to be a perfect plug flow reactor, the other was the tanks-in-series mill model. Table 5.18 compares measured with simulated data. Agreement is good, with the tanks-in-series model holding a slight edge.

TABLE 5.18 Summary of Overall Simulating Results of the Actual Grinding Circuit Operating at 154.2 mtph.

Quantity	Measured	Plug Flow	Tanks-in-Series
circulating load, %	163	156.90	164.97
% -200 mesh, COF	62.90	61.99	61.64
mean residence time τ, min	3.11	3.27	3.19

CHAPTER VI

DISCUSSION

6.1 Laboratory

6.1.1 Silica

The main objective was the development of a suitable experimental technique. This meant first developing a reliable screening procedure but more specifically determining the reproducibility and comparing the one-sample-at-a-time with recycle techniques. Some preliminary exploration of void filling and particle size was also conducted. The experimental conditions are considered first.

The screening procedure adopted was a wet-dry technique which is well suited to the later wet milling of the Pb/Zn samples. A dry screening time of 20 min. proved adequate.

Reproducibility was tested in Figure 5.12. This was the recycle method with a synthetic sample made to have identical mass and size distribution. The data is reproduced to within 0.7% absolute.

It was necessary to compare the recycle with the one-sample-at-a-time procedure because of the nature of the Pb/Zn experiments. In these experiments, samples must be removed for assaying and so cannot be recycled. Since ten size fractions are taken and about 2 g is required for each assay, after, for example, five grind tests about 100 g would have been removed from the recycle. This was judged to be excessive and although the recycle method is convenient[54], for present purposes the more difficult one-sample-at-a-time procedure was adopted.

To avoid sampling bias in preparation of the testing material, synthetic samples were prepared to have identical mass and size distribution. Figures 5.2 and 5.8 show that both techniques yield indistinguishable results. Thus the one-at-a-time method was approached with confidence.

Incidently, the correlation between the two techniques also indicates that mixing in the recycle method is not a severe problem. It was felt at the onset that upon the start of grinding, a certain time might elapse for mixing before 'real' grinding took place. This is equivalent to a dead-time. If this were the case, the recycle method would exaggerate the dead-time. This does not appear to be the situation.

The void filling conditions were investigated with experiments 3 to 6. The results are in agreement with those reported recently[8], i.e. slower rate of breakage for higher void filling. The feed particle size distribution effect was also investigated, the results of experiments 4 and 5 show that the single size feed breaks, in general, slower than an initially natural particle size assemblage.

6.1.2 Pb/Zn Ore

The Pb/Zn samples clearly could not be generated synthetically which is the ideal for the one-sample-at-a-time procedure. The spinning riffler was employed and as indicated gave samples differing in mass by less than 1.69% and sizes varying by less than 0.58% absolute. The small variation in head assay reported in Table 5.10 indicates the riffler also split accurately on a component basis.

Due to the large amount of information, grinding parameters were generated from a computer program. This program was written to exclude t = 0 in the regression as in the p-order case log (0) cannot be computed. This is of some consequence in first order kinetics, but since little use is made of this order, the omission is not important.

The superior fit of the p-order model is well illustrated in Figure 5.25. Given that the harder and coarser silica was fitted (reasonably) by first order up to +10 mesh, the difference in the Pb/Zn experiments requires some explanation.

The principle reason is probably that the metal assaying fails to differentiate between liberated and locked mineral grains. Consequently, the detected grinding kinetics is some combination of two events, the rate with which liberated mineral disappears and the rate with which the mineral in the locked grain disappears. Even if both disappearances follow first order, the sum clearly will not. Without information on the degree of locking it is impossible to decouple the two events. The p-order fit is a convenient resolution of the problem. (It should be stressed that fitting by p-order does not depend on the separate events following first order. What matters is that p-order fits well, and to that extent, it is purely empirical.)

The argument readily applies to individual minerals but not the overall. It is interesting that overall kinetics approaches quite closely first order even at coarse (+28 mesh) sizes. What is clearly a complex phenomena on a mineral-by-mineral basis, nevertheless, seems describable on an overall basis by first order.

The RMD grinding experiments were performed as a preliminary investigation of the role of size distribution and mineral composition on the kinetics. Figure 5.26 acts as a summary of the findings.

The first impression is that there is considerable similarity; for example, the range in the rate-of-breakage and the relative values for each mineral. In detail some differences are apparent, for instance the tendency for the components in the RMD results to approach the same values at the finer sizes. The CUF results tend to be a little higher at the coarse end.

The differences are not as large as were expected for such different streams. In fact, substituting parameters derived from the RMD experiments did not materially affect the simulation. Nevertheless it is felt that the parameters are best derived from the material being ground rather than using material from another stream. This observation is directed particularly at attempts to derive grinding parameters from a sample of ore rather than ball mill feed when dealing with highly heterogeneous ores.

6.2 Plant

6.2.1 Data Adjustment

Adjustment of the plant data to yield internally consistent mass/size/chemical assays was basic to the development of the simulator. The adjusted data represents the reference which must be simulated before the proposed circuit can be evaluated.

The adjustment technique was developed from that described by Lynch.[42.b] The contribution in the present work was the adjustment of the overall mineral composition in each stream.

This technique may be considered as the first in a series of ever more sophisticated techniques, some of which are described in a recent report by Lyman.[62] Techniques for simultaneous estimation of α and data adjustment are more powerful. Some require extensive computing ability. One of the most successful appears to be that recently described by Hodouin et al.[32]

The present choice, nevertheless remains convenient and as Lynch notes[42.b] given good original data, the less complex the data treatment the better. The adjustment observed for the two cases (154.2 and 190.3 mtph) reveals only slight size adjustments were required with somewhat greater chemical adjustments. Although care is required in arguing back from the result, it appears the present data, corresponded to 'good original data'.

6.2.2 Plant Derived Ball Mill Model

A logical place to search for a ball mill model is the full size ball mill itself. A preliminary approach was proposed by considering first order breakage kinetics and estimating τ from the mill pulp hold-up volume and CUF volumetric pulp flow rate. The high correlation between k_i and d for both tonnages must be considered a significant encouragement to this approach.

The implication is that kinetics are linear and independent of mill throughput. Further, treating the kinetics with a single cumulative-basis k_i is a great simplification over the conventional 'S and B' model. The limitation of the approach is that the k_i values must depend on the particle size distribution; they are not unique, therefore, in the manner of S and B. However, if the size distribution does not change greatly, describing by k_i alone is justifiable.

Experience with grinding circuits does indicate that the size distributions of the streams does not change greatly upon operating changes. Consider the present case. At 154.2 mtph the CUF overall size was 31.28% -200 mesh, whereas at 190.3 mtph, with a different mineral composition, the overall size was 32.26% -200 mesh. Not a large difference and by implication from the present findings, not large enough to invalidate k_i. The laboratory experiments with the RMD suggest that even larger size distribution shifts can be tolerated.

For modelling an existing plant, a cumulative rate-of-breakage is probably adequate, and is certainly simpler than the conventional procedure.

The argument regarding k_i notwithstanding, extension to a mineral-by-mineral description was not successful. The approach will be of direct application when overall size reduction is of major concern. This will be true for homogeneous ores and ores where valuable mineral content is so low that describing it separately is not initially justified (e.g. porphory copper/molybdenum ores).

6.2.3 Plant Derived Cyclone Model

The cyclone performance curves are similar to those reported earlier for this circuit, as are the $d_{50(C)m}$, n_m and a_m values.[41] At 190.3 mtph a somewhat different behaviour of the higher density components, pyrite and galena, is noted. The short-circuiting to underflow is much greater than expected. This may reflect heavy media effects at high loads of high density minerals, giving poor size splitting performance.[41]

6.3 Simulation

6.3.1 Actual Circuit

Taking the ball mill alone or the Y matrix cyclone model of the full circuit, it is possible to judge the fitting obtained using the laboratory derived grinding kinetics. Remarkably, the overall and all the minerals, with the exception of galena, are fitted without resort to the scaling factor Fg_m.

This appears to be in contrast to the scaling suggested by Austin who derived $S \propto (D)^{0.6}$ where D is mill diameter. Although the cumulative rate of breakage in the present case is not equal to S, the dependence on operating variables, such as mill diameter, should be the same, if B is independent of D.[19] The relationship between S and D is probably more complex than suggested by Austin, as the recent work of Hodouin et al. shows.[32]

The tentative explanation for $Fg_m = 1$ is that if the energy per ton is equivalent in both the laboratory and plant cases, the size reduction will be the same[61.b], and hence the grinding parameters derived will be the same. It is suggested that this equivalence in energy/unit mass has been achieved. This is a consequence of the careful matching of laboratory and plant milling conditions and employing ball mill feed as opposed to an ore sample.

The grinding factor of 0.7 for galena merits separate attention. Some uncertainty necessarily exists when considering such small quantities of material. But, the observation is substantiated by both tonnage cases, and is therefore considered real.

The problem can be succinctly stated: why does galena, alone of all the minerals, break more slowly in the plant mill compared with the laboratory mill?

A search of the literature suggested two possibilities: buffering and transport effects.

Remenyi[24], reviewing data on grinding of mixtures, introduced the concept of buffering, whereby a fine soft mineral is protected from breakage (buffered) by a coarse harder mineral. This condition is met in the present case as the cyclone produces a fine galena and coarse calcite/dolomite ball mill feed. Buffering in a large mill has apparently been observed.[41] However, the question then arises as to why buffering, at least to the extent apparent in the full-size mill, is not found in the laboratory?

Transport effects may be a prime factor. In the small laboratory mill, fully mixed conditions are probably approached. Indeed, the balls will act to aid mixing.[63,64] In the large mill segregation may be occurring due to particle size and density differences. It is tentatively postulated that the galena settles below the main impact zone in the ball mill, where most grinding is considered to take place.[61.c] The galena becomes shielded by the lighter components, which is a form of buffering.

This explanation could be subjected to experimental confirmation in the laboratory.

6.3.2 Proposed Circuit

The predicted performance of the proposed circuit has made use of the flotation recovery matrix graphically illustrated in Figure 5.27, for both throughput cases of 154.2 and 190.3 mtph. This matrix was judged to be reasonable, given that the flotation tests had to be carried out on ball mill discharge from the existing circuit which is quite different in PbS content from the steady state BMD in the proposed circuit.

Considering the above only as a small cautionary note, the following discusses the results obtained. Table 5.17 and Figures 5.41 and 5.42, show the most outstanding results. It can be seen that the first objective of the design change has largely been achieved. That is, a significantly coarser PbS has been produced and the circulating load reduced. In both tonnages the coarsening has been greater than 40% absolute on the -200 mesh fraction. The new circulating loads become about the same as for the overall.

It is important to note that the design change has not affected the size reduction of the other minerals. This is the result, in the first instance, of the relatively small volumetric contribution of PbS in the circuit and hence a small variation in the mean residence time and also because the flotation stage is very selective in removing PbS.

An unexpected result, is the increased across-the-circuit recovery of PbS compared with the recovery across-the-cell alone (Table 5.17). The reason is that the cyclone scavenges the flotation tails (and fresh feed), preferentially recycling galena back to the cell. The description scavenger is carefully chosen as the term compares the cyclone contribution to the overall PbS recovery with that of a true scavenger flotation stage. The cyclone effect is the same, although exploiting galena density rather than floatability. The difference is one simply of degree, the scavenger flotation can be tuned to be more selective.

An important practical aspect is the low concentrate grade predicted at steady state; about 36% Pb in both cases. Reference to Figure 5.27 will indicate the original data showed a 76% Pb grade, a grade practically sufficient for final concentrate. However attractive the 76% Pb may seem it results from on an artificially high Pb feed, that existing in the actual circuit. This Pb is selectively bled in the proposed circuit. Thus Pb content in flotation feed (BMD) decreases while the other minerals remain much the same. For the same recovery-size matrix the effect is a reduced quantity of PbS diverted to concentrate while roughly the same quantity of other components is diverted. Consequently, the grade of Pb decreases.

The conclusion is that it will be difficult to achieve a high grade Pb concentrate without a severe depressing environment for Zn coupled with short flotation times and consequently low Pb recovery at this stage resulting in less coarsening of the final product. It should not, however, be impossible to clean this flotation concentrate. After all, it is not usual to expect a roughing step, which is what this flotation stage most closely resembles, to provide finished grade.

The reader may have noticed that different total recoveries are given for each tonnage which are in turn different from those given for the laboratory data. This illustrates the effect of mineral size distribution. For the same recovery-size matrix, different feed size distributions yield different total recoveries.

This may sound trivial, but the recently described closed circuit simulation proposed by Agar et al.[66] using a single, total recovery (or split) factor does not recognize the importance of this feed size distribution.

6.3.3 Other Possible Applications

Flotation of ball mill discharge is simply an application of perhaps the only general rule in mineral processing: remove the values at the earliest possible stage. The technique is of use whenever a build-up of one component in the closed circuit occurs. This is usually because of density effects but could be due to slow breakage of the component. Applications in mercury sulphide, cassiterite, gold and wolframite circuits are obvious cases, and some examples of the application exist.

Interestingly, a detailed examination of the effect of such a circuit change has not been reported until now. A private communication with A. Hinde, Chamber of Mines, South Africa, indicated that a detailed analysis has just been conducted on a gold milling circuit. The advantage sought was to provide a preconcentrate underground which could be pumped to the surface, thus saving on hoisting costs from deep mines. Some of the effects noted are similar to those here; for example, the added recovery due to the cyclone scavenging action. In that case, a gold circuit recovery of 98% was realized for 75% recovery across the cell, yielding a cyclone overflow barren enough for mine back-fill.

CHAPTER VII

CONCLUSIONS

SILICA EXPERIMENTS

1. Cumulative first-order grinding kinetics gave adequate fitting.
2. The recycling and one-at-a-time grinding procedures gave the same result.
3. The top size and single size procedures gave different grinding parameters.

Pb/Zn EXPERIMENTS

1. Overall grinding was fitted by a cumulative first-order; mineral-by-mineral by p-order.
2. p-order was required as breakage of mineral in free and locked form cannot be distinguished.
3. CUF and RMD materials gave similar kinetics with the RMD being a little slower at the coarser sizes.
4. From instantaneous rate-of-breakage galena breaks fastest (except for the finest fractions) followed by sphalerite, calcite/dolomite and finally, pyrite.

PLANT DATA

1. A technique for mass-balancing and data adjustment size-by-size mineral-by-mineral was developed based on that described by Lynch.

2. Adjustment of sizes was less than 1.5%, and of mineral assays less than 0.29% (absolute).
3. From the ball mill feed and ball mill discharge data, a cumulative rate-of-breakage (overall) was determined assuming first-order kinetics. It was observed that:
   (i) k was independent of throughput; and
   (ii) k was correlated with particle size by

$$k = 9.18\text{x}10^{-4}.d^{1.043}$$

   with k in min^{-1} and d in μm.
4. The observation reported in 3. did not apply to mineral-by-mineral breakage.
5. Cyclone performance curves, overall and mineral-by-mineral were similar to previous observation. The $d_{50(C)m}$ could be correlated with mineral density.

SIMULATION OF BALL MILL

1. A p-order plug flow ball mill model with laboratory determined parameters was a suitable fit with a scaling factor required only for galena.
2. The lack of scaling suggested equivalence of energy/tonne for both laboratory and full size mill was approached. This reflects the attempted similarity of mill filling conditions.

3. Scaling for galena indicates galena breaks more slowly in large mill perhaps because of its density causing it to follow a transport path below the main impact zone.
4. Overall breakage using the p-order and tanks-in-series model suggested the latter offers minimal improvement.

SIMULATION OF ACTUAL CIRCUIT

1. The p-order plug flow ball mill model and Y matrix model gave adequate simulation at both 154.2 and 190.3 mtph. This is significant as laboratory tests were conducted only on material isolated from CUF at 154.2 mtph.
2. A method of combining the Lynch, Plitt and Finch/Matwijenko models into a full cyclone model was described. With present data, fitting is not adequate.

PREDICTED CIRCUIT PERFORMANCE

1. The circuit is successful in reducing circulation of galena and coarsening galena product. Coarsening by up to 40% on the -200 mesh fraction is predicted, given the flotation recovery-size matrix used.
2. Pb recovery across the circuit is much higher than across flotation cell alone, up to 30% higher. This is the result of scavenging action of cyclone on galena.
3. Grade of flotation concentrate is lower than laboratory tests indicate on BMD from existing circuit because proposed circuit reduces Pb content in BMD.

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APPENDIX I

METHODS TO DETERMINE B(x,y) AND S(x)

The Single-Size and Top-Size Methods

The methods were originally proposed by Sedlatschek and von Bass (as quoted by Gardner[66]). The single-size method consists of the following:

(a) Removal of all material except the size of interest and, grinding for a short period of time.

(b) Sieving, weighing and calculating the ratios of weights that appear in any lower size x to the total weight which is ground out of the size in question.

(c) Repeating (a) and (b) for several size fractions.

The breakage function B(x,y) is given by the ratio calculated in (b). The selection for breakage function S(y) where y is the size of interest, can be determined by forming the ratio: fractional weight disappearance of particles of size y divided by the short period of time of grinding. The top-size method is used only to determine the selection function or specific rate of breakage, S(x).[8,34,58]

Both methods are suspect because they do not replicate the natural grinding environment of real systems of grinding in which the whole size range of particles is being broken.

The Tracer Method

Gardner and Austin[59] were the first to report this method. It consists of the following:

(a) Removing the mass-size fraction of interest.

(b) This fraction is tagged with a radioactive tracer and re-mixed with the original charge.

(c) Grinding for a short period of time.

The breakage functions are obtained by forming the ratios of the mass retained on smaller sizes to the total mass of tagged material. Steps (a) to (b) are repeated for each particle size.

The selection function can be estimated and is equal to the fractional amount of tracer disappearance in the traced size per unit time. The method proposed is better than the previous methods because of one main reason: the traced material breaks in its natural grinding environment.

The Back-Calculation Method

This is the method III reported by L.G. Austin and P.T. Luckie.[59] Using their own words: "In principle, the size distribution produced at some time of grinding is a unique result of the S and B parameters, and knowing S, B can be back-calculated."

The details of this method are beyond the scope of this work. Nevertheless, it is worth emphasizing that this particular method is being used for estimating B for continuous large scale grinding simulations.[20,23,32]

APPENDIX II

STANDARD CHEMICAL ANALYSIS PROCEDURE

The procedure adopted in the chemical analysis work was as follows:

(a) Pulverizing the four coarsest screened materials (28, 35, 48 and 65 mesh).

(b) Weighing suitable amount of sample to avoid excessive dilution ratios. Depending on the sulphide content, the weight samples ranged from approximately 0.100 to 0.200 g.

(c) Dissolving of the samples was as follows:

i) In a 250 ml beaker adding 5 ml of distilled water, 5 ml of hydrocloric acid (HCl), 5 ml of nitric acid (HNO_3), and 1 ml of perchloric acid ($HClO_4$).

ii) Heating on the hot plate until dryness.

iii) Addition of 5 ml of distillated water and 10 ml of hydrochloric acid (HCl).

iv) Heating until dissolution.

v) Filtering using Warman filter paper; the filtrate going to a 250 ml volumetric flask and the filter paper discarded.

(d) Atomic absorption spectrophotometer. Dissolved samples of known overall concentration in ppm, were analysed according to the following procedure:

i) Lead (Pb). Diluted samples, prepared according to section iii) above, were analysed using the optimum range of concentration of 2.25 ppm recommended by the Analyser's Manual. The standards were: 6, 10, 15, 20, and 25 ppm of lead. The instrumental conditions were:

slit setting:	0.4 nm
wavelength:	283.31 nm
lamp current:	5-6 mA
air flow rate:	5 lt min^{-1}
fuel (acetylene) flow rate:	1.0 lt min^{-1}

ii) Zinc (Zn). The samples of primary dilution were further diluted in order to achieve the optimum range of 0.2-0.3 ppm for zinc. The standards used were: 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 ppm of zinc. The instrumental conditions were:

slit setting:	0.4 nm
wavelength:	213.86 nm
lamp current:	8-10 mA
air flow rate:	5.0 lt min^{-1}
fuel (acetylene) flow rate:	1.1 lt min^{-1}

iii) Iron (Fe). This analysis was made on the same samples for zinc determination. The optimum range of concentration of the instrument is 0.5-10 ppm of Fe. The standards used: 1, 2, 3, 4, 5 and 8 ppm of iron. The operation settings:

slit:	0.4 nm
wavelength:	248.33 nm
lamp current:	12-15 mA
air flow rate:	5.0 lt min^{-1}
fuel (acetylene) flow rate:	1.0 lt min^{-1}

(e) Plotting calibration curves for each element (standard ppm against absorbance readings).

(f) Use of least squares technique to obtain interpolation of concentrations. Figure A2.1 to Figure A2.3 show three typical calibration curves for lead, zinc and iron. Also shown are the equations of the lines obtained using least squares technique.

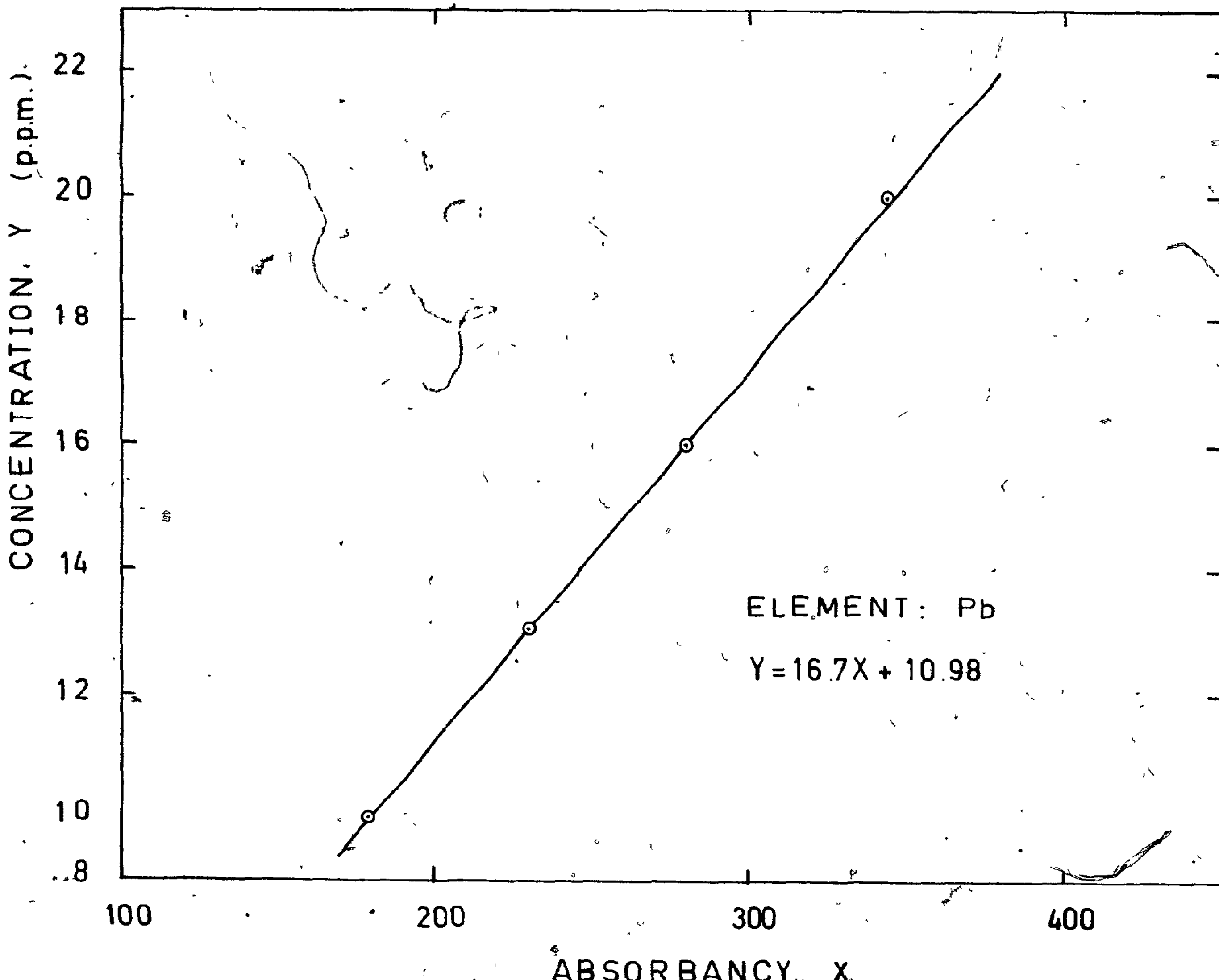
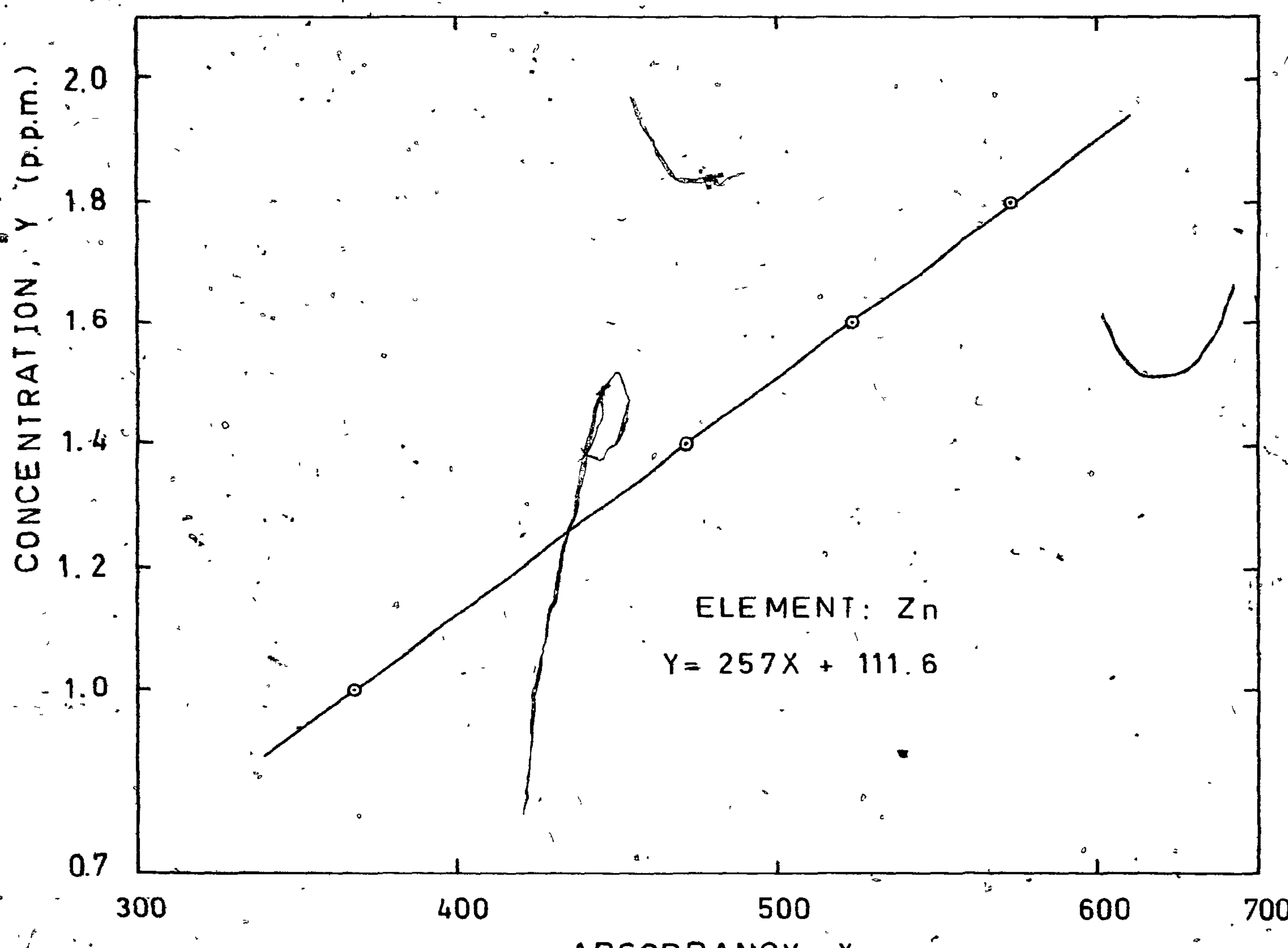
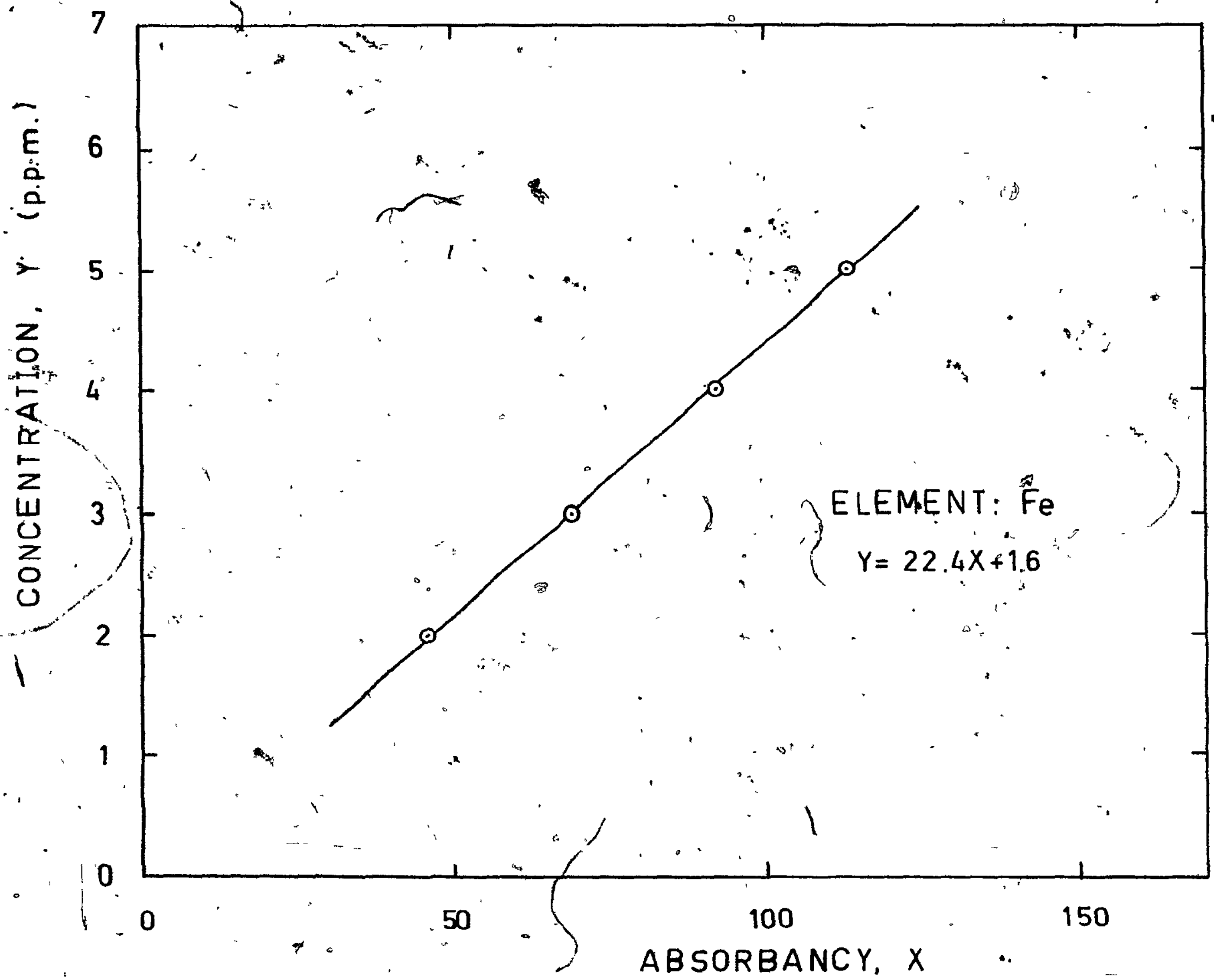

22
20
18
16
14
12
10
8
CONCENTRATION, Y (p.p.m.)
100
200
300
400
ABSORBANCY, X
ELEMENT: Pb
Y = 16.7X + 10.98

FIGURE A2.1



2.0
1.8
1.6
1.4
1.2
1.0
0.7
CONCENTRATION, Y (p.p.m.)
300
400
500
600
700
ABSORBANCY, X
ELEMENT: Zn
Y= 257X + 111.6

FIGURE A2.2



7
6
5
4
3
2
1
0
CONCENTRATION, Y (p.p.m.)
0
50
100
150
ABSORBANCY, X
ELEMENT: Fe
Y= 22.4X+1.6

FIGURE A2.3

APPENDIX III

MISCELLANEOUS DATA AND BATCH GRINDING MILL CALCULATIONS

III.1 Screening

Table III.1 shows the $\sqrt{2}$ size ratio screen aperture of screens used in the grinding experiments.

Figure A3.1 shows in the Schuhmann plot, the optimum screening time found in dry screening silica in the Ro-Tap machine. Twenty minutes is the optimum; any longer screening time would produce size reduction by abrasion[34], thus masking the real size assays.

III.2 Batch Mill Loading and Speed Calculations

For both the silica and the Pb-Zn ore grinding experiments, the same ball charge was used. The assumptions made, along with the following data, the number of balls and mineral charge to the mill were computed; also computed are the critical velocity and percent of critical velocity of the mill.

DATA

diameter of mill, $D = 20.32$ cm (8") (D_f 0.66')

length of mill, $L = 16.51$ cm (6-1/2")

diameter of grind balls, $d = 2.54$ cm (1")

speed of mill, $S_b = 57$ rpm

TABLE A3.1 Screens Series Specifications.
Opening Ratio: $\sqrt{2}$.
Opening Base: .075 mm (200 mesh Tyler Screen)

Screen Number	Canadian Tyler Standard Screen Number	Tyler Standard Equivalent	Opening mm
1	6	6	3.360
2	8	8	2.380
3	10	10	1.651
4	14	12	1.400
5	16	14	1.180
6	20	20	0.841
7	30	28	0.595
8	40	35	0.425
9	50	48	0.300
10	70	65	0.212
11	100	100	0.150
12	140	150	0.106
13	200	200	0.075
14	270	270	0.053
15	400	400	0.038

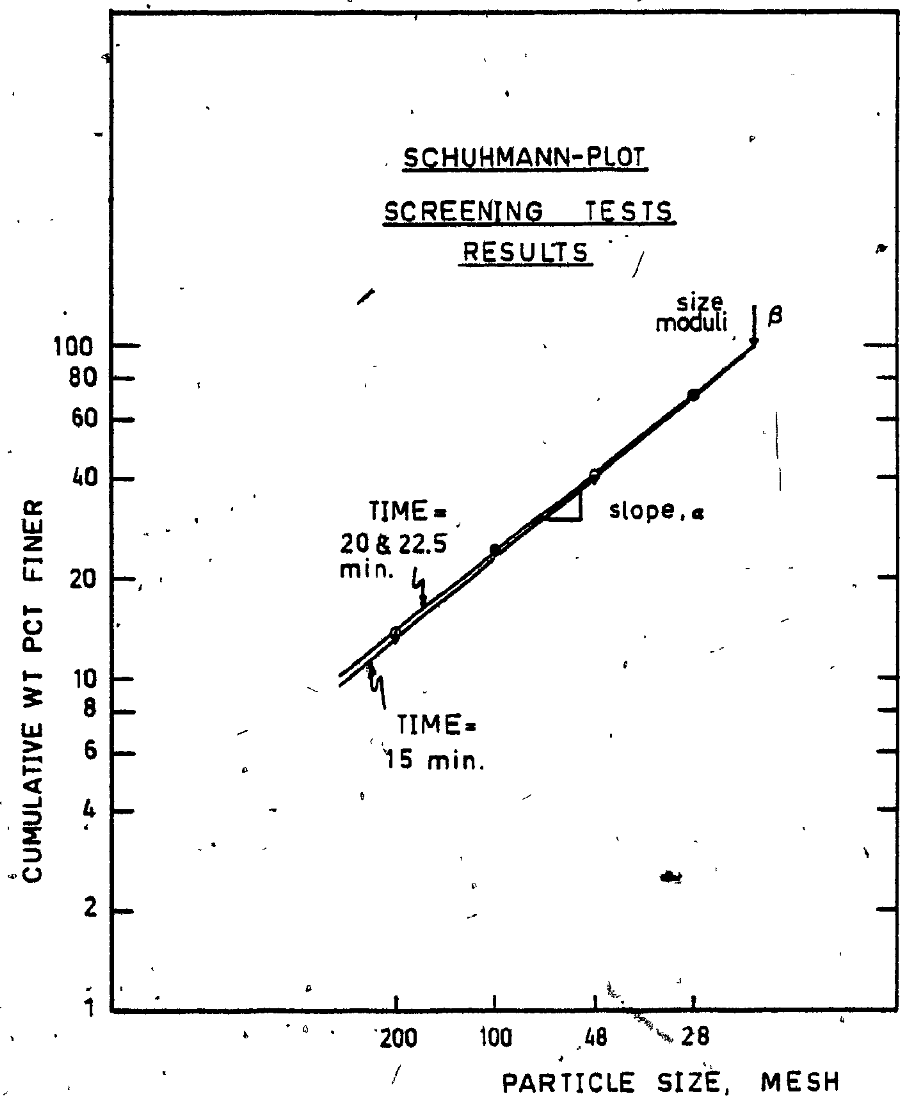

SCHUHMANN-PLOT
SCREENING TESTS
RESULTS
size moduli
β
100
80
60
40
20
10
8
6
4
2
1
TIME = 20 & 22.5 min.
slope, α
TIME = 15 min.
CUMULATIVE WT PCT FINER
200
100
48
28
PARTICLE SIZE, MESH

FIGURE A3.1

ASSUMPTIONS

1. voids, volume percent of internal mill volume, $v = 12\%$.[8]
2. voidage between balls, $p = 38\%$.[60,61]

CALCULATIONS

$$V_T = \frac{\pi}{4} D^2 . L = 5340 \text{ cm}^3$$

$$V_v = v . V_T/100 = 640.8 \text{ cm}^3$$

$$V_b = \pi d^3/6 = 8.58 \text{ cm}^3$$

$$N_b = V_{bt}/V_b = 196 \text{ balls}$$

$$S_c = 76.6\ D_f^{-\frac{1}{2}} = 93.8 \text{ rpm}$$

$$S_{bc} = 100\ S_b/S_c = 68.7\%$$

where:
- V_T = internal ball mill volume
- V_{bt} = volume of balls
- V_b = volume of one ball
- N_b = number of balls of one charge
- S_c = critical speed, in rpm
- S_b = speed of the mill, in rpm
- S_{bc} = percent of the critical speed
- D_f = diameter of the mill, in feet

III.2.1 Calculation of the Charge of Silica to the Mill

Depending on the voids percent filling chosen, the weight of silica for each dry batch grinding experiment is calculated using the bulk density. The calculation is as follows:

$$\text{weight of silica (one charge)}, \; WT_{SiO_2} = \rho_b \cdot V_v \cdot v_p/100$$

where: WT_{SiO_2} is the weight of silica, in g

ρ_b is the bulk density of silica, in g/cm^3 (= 1.6)

V_v is the voids volume (= 0.12 V_T), in cm^3

v_p is the percent of voids volume filled with silica

III.2.2 Calculation of the Pb-Zn Ore Charges for the Wet Batch Grind Experiments

The weight of dry solids and water for the CUF and RMD experiments are calculated using the previous balls charge calculations (196 balls). The assumptions are the following:

Assumption No. 1: pulp dilution is given by 42.13% solids by volume for both materials.

Assumption No. 2: the pulp volume is 120% of the voids volume.

DATA

$$V_v = 640.8 \text{ cm}^3$$

$$V_{slurry} = 1.2 \, V_v \cong 769 \text{ cm}^3$$

$$S_v = 42.13\%$$

$$\rho_{CUF} = 3.53 \text{ g/cm}^3$$

$$\rho_{RMD} = 3.08 \text{ g/cm}^3$$

CALCULATIONS

$$S_v = \frac{V_{ore}}{V_{ore} + V_{H_2O}} \times 100$$

$$V_{slurry} = V_{ore} + V_{H_2O}$$

$$\therefore V_{ore} = \frac{S_v \cdot V_{slurry}}{100} \simeq 324 \text{ cm}^3$$

$$W_{ore} = \rho_{ore} \cdot V_{ore}$$

$$W_{CUF} = \rho_{CUF} \cdot V_{ore} = 3.53 \times 324 \simeq 1144 \text{ g}$$

$$W_{RMD} = \rho_{RMD} \cdot V_{ore} = 3.08 \times 324 \simeq 998 \text{ g}$$

$$W_{H_2O} = V_{H_2O} = V_{slurry} - V_{ore} = 769 - 324 = 445 \text{ cm}^3$$

(for CUF and RMD)

$$S_p = \frac{W_{ore}}{W_{ore} + W_{H_2O}} \times 100 \quad \text{(PCT solids by weight)}$$

$$S_{p_{CUF}} = \frac{1144}{1144 + 445} \times 100 \simeq 72.0\%$$

$$S_{p_{RMD}} = \frac{998}{998 + 445} \times 100 \simeq 69.2\%$$

III.3 Calculation of Volumetric Ball Mill Holdup

The calculations use the geometry of the mill. Certain assumptions are made as well as follows:

Assumption 1

The diameter of the overflow orifice is 0.6096 m (2').

Assumption 2

The level of balls (at rest) coincides with the edge of the overflow orifice.

Assumption 3

The ball packaging factor is 0.38 (the hexagonal compact).[60]

Assumption 4

The pulp volume occupies 120% of the interstitial volume between balls (at rest). This assumption accounts for the volume of the flying balls replaced by the pulp (mill in motion).

DATA

$D = 3.505$ m (11.5')

$d = 0.609$ m (2')

$\ell = 4.876$ m (16')

$r = D/2 = 1.752$ m (5.75')

$r' = d/2 = 0.304$ m (1')

Calculation of Volume of Mill, V_T

$$V_T = \pi/4 \cdot D^2 \cdot \ell$$

$$= 47.060 \text{ m}^3$$

Calculation of Volume, V_b

Calculation of Area, A

$$A = 1/2\, r^2(\theta - \sin\theta)$$

$$\theta = 180^o - 2\alpha$$

$$\alpha = \sin^{-1}(\frac{r'}{r})$$

$$\alpha = 10.01^o = 0.1748 \text{ radians}$$

$$\beta = 159.98^o = 2.7919 \text{ radians}$$

$$\therefore A = 3.762 \text{ m}^2$$

Finally,

$$V_b = A \cdot \ell = 18.347 \text{ m}^3 \simeq 39\% \ V_T$$

$$= \text{balls bulk volume}$$

Calculation of Interstitial Space Between Balls, V_v

$$V_v = V \cdot 0.38$$

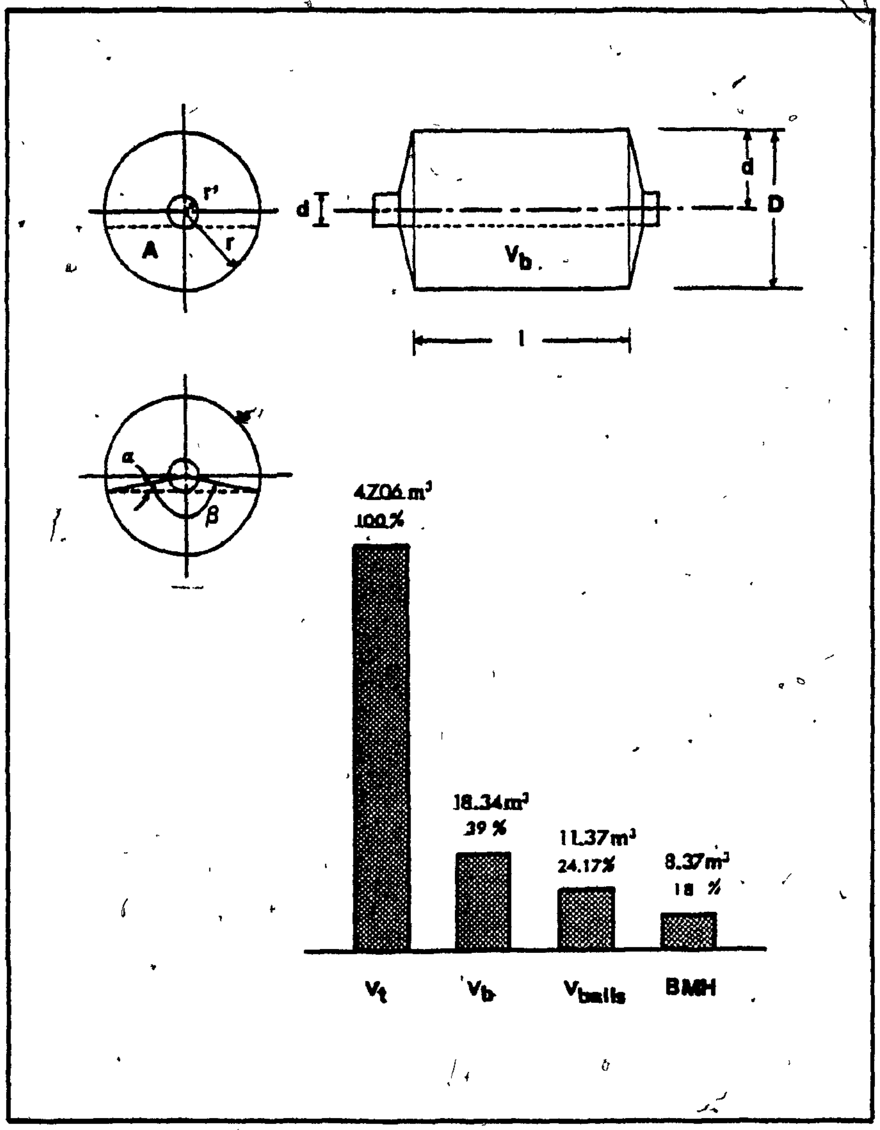
$$= 6.972 \ m^3$$

Calculation of Volumetric Ball Mill Holdup, BMH

$$BMH = 1.2 \cdot V_v$$

$$= 8.366 \ m^3 \cong 18\% \ V_T$$

Figure A3.2 shows graphically V_T, V_b, V_{balls} and BMH. These volumes are also expressed in percent of V_T, the total internal volume of the mill.



r'
r
A
d
d
D
V_b
l
α
β
47.06 m³
100 %
18.34m³
39 %
11.37m³
24.17%
8.37m³
18 %
V_t
V_b
V_{balls}
BMH

FIGURE A3.2

APPENDIX IV

CONTENT

SECTION IV.1

SECTION IV.2

Computer Program to Adjust the Size and Chemical Assays of the Raw Data Gathered from a Sampling Campaign of the Closed Grinding Circuit.

EXPERIMENTAL RESULTS - BATCH GRINDING OF A PB-ZN ORE

MATERIAL: CYCLONE UNDERFLOW

WEIGHT RETAINED, GR

MESH NO	SIZE MICR	FEED	2 MIN	4 MIN	6 MIN	8 MIN	10 MIN	12 MIN
28	599	12.40	3.52	1.56	0.65	0.59	0.28	0.36
35	425	6.76	2.66	0.76	0.23	0.16	0.07	[illegible]
48	300	9.18	6.11	2.83	1.08	0.66	0.22	0.17
65	212	8.48	7.60	5.52	3.17	2.59	1.22	[illegible]
100	148	12.37	13.21	12.13	9.40	11.54	7.39	[illegible]
150	106	13.64	15.63	16.48	15.52	26.68	21.14	32.77
200	75	10.03	12.26	14.11	14.89	[illegible]	29.78	57.39
270	53	6.99	9.73	11.73	[illegible]	29.13	[illegible]	[illegible]
400	37	2.95	4.27	5.51	6.57	14.64	[illegible]	35.14
-400	-37	11.79	[illegible]	23.52	27.98	63.86	72.79	161.11

PERCENT RETAINED

MESH NO	SIZE MICR	FEED	2 MIN	4 MIN	6 MIN	8 MIN	10 MIN	12 MIN
28	598	13.12	3.83	1.66	0.70	0.33	0.15	[illegible]
35	425	7.15	2.89	0.83	0.25	0.09	0.14	[illegible]
48	300	9.71	6.64	3.01	1.16	0.37	0.12	[illegible]
65	212	8.97	8.26	5.86	3.41	1.44	0.67	[illegible]
100	148	13.09	14.36	12.88	10.12	6.42	[illegible]	[illegible]
150	106	14.43	16.99	[illegible]	16.71	14.83	11.62	[illegible]
200	75	10.61	13.33	14.97	16.02	[illegible]	16.39	15.78
270	53	7.40	[illegible]	12.46	14.43	[illegible]	17.54	18.43
400	37	3.12	[illegible]	5.85	[illegible]	8.14	9.39	9.66
-400	-37	12.38	18.43	24.98	[illegible]	35.51	[illegible]	44.31

OVERALL PB-ZN ORE - CUMULATIVE WT PCT RETAINED

MESH NO	SIZE MICR	FEED	2 MIN	4 MIN	6 MIN	8 MIN	10 MIN	12 MIN
28	598	13.12	3.83	1.66	[illegible]	0.33	[illegible]	0.10
35	425	20.28	6.72	2.49	0.95	0.42	0.19	0.11
48	300	29.99	13.36	5.49	2.11	0.78	0.31	0.16
65	212	38.96	21.62	11.35	5.52	2.22	0.98	0.45
100	148	52.05	35.98	24.24	15.64	8.64	[illegible]	[illegible]
150	106	66.49	52.97	41.74	32.35	23.48	16.67	11.82
200	75	77.10	[illegible]	56.71	48.37	40.16	33.05	27.60
270	53	84.50	76.88	69.17	62.80	56.35	50.59	46.03
400	37	87.62	81.52	75.02	69.88	64.49	59.57	55.69

EXPERIMENTAL RESULTS - BATCH GRINDING OF A PB-ZN ORE

MATERIAL: CYCLONE UNDERFLOW

ELEMENT: LEAD ASSAYS,PCT

MESH NO	SIZE MICR	FEED	2 MIN	4 MIN	6 MIN	8 MIN	10 MIN	12 MIN
28	598	1.64	1.15	0.93	1.02	0.87	0.69	0.58
35	425	2.24	1.76	0.72	1.02	0.87	0.69	0.58
48	300	2.19	1.83	1.45	0.90	0.95	0.39	0.41
65	212	2.74	2.70	1.98	1.48	1.35	0.87	0.72
100	148	4.20	4.00	2.84	2.73	2.68	2.09	1.83
150	106	6.29	5.41	4.67	3.34	3.83	3.72	2.99
200	75	11.94	6.69	6.11	4.39	5.93	5.40	4.35
270	53	15.60	12.21	9.80	10.75	6.89	6.68	6.92
400	37	13.66	11.05	9.72	8.06	8.48	8.49	6.31
-400	-37	6.09	6.01	6.22	5.63	5.98	5.75	5.96

ELEMENT: ZINC ASSAYS,PCT

MESH NO	SIZE MICR	FEED	2 MIN	4 MIN	6 MIN	8 MIN	10 MIN	12 MIN
28	598	6.98	5.89	4.54	4.60	2.27	3.27	2.47
35	425	6.46	5.69	5.29	4.60	2.27	3.27	2.47
48	300	7.92	6.23	5.80	4.08	3.66	1.71	2.22
65	212	9.20	8.87	7.66	6.64	5.96	4.65	4.41
100	148	11.95	11.56	10.83	11.28	13.46	9.49	8.92
150	106	12.26	12.21	11.26	10.37	11.09	10.25	12.93
200	75	8.42	9.12	8.41	10.56	9.25	8.67	8.36
270	53	6.49	8.23	8.18	8.25	8.56	9.37	8.69
400	37	6.63	7.42	7.68	7.69	8.36	8.37	8.64
-400	-37	7.31	7.95	7.88	7.94	8.32	8.48	8.21

ELEMENT: IRON ASSAYS,PCT

MESH NO	SIZE MICR	FEED	2 MIN	4 MIN	6 MIN	8 MIN	10 MIN	12 MIN
28	598	11.13	12.71	16.19	23.49	28.92	27.32	26.20
35	425	10.88	14.23	20.92	23.49	28.92	27.32	26.20
48	300	14.89	13.83	18.94	22.35	23.26	29.11	30.61
65	212	14.89	14.20	16.74	19.41	20.17	22.36	24.16
100	148	22.67	17.30	16.95	17.89	23.13	20.43	22.83
150	106	21.15	22.59	20.57	19.31	21.02	22.36	20.22
200	75	21.04	18.03	17.17	20.96	20.37	19.52	18.94
270	53	12.14	12.00	12.92	14.76	14.60	15.82	16.39
400	37	10.12	10.29	9.51	9.52	12.04	13.33	13.11
-400	-37	10.13	10.26	10.54	10.88	11.69	11.94	12.61

EXPERIMENTAL RESULTS - BATCH GRINDING OF A PB-ZN ORE

MATERIAL: CYCLONE UNDERFLOW
[illegible]

ELEMENT: LEAD FREQUENCY DISTRIBUTION, PCT

MESH NO	SIZE MICR	FEED	2 MIN	4 MIN	6 MIN	8 MIN	10 MIN	12 MIN
28	598	3.65	0.77	0.27	0.13	0.06	0.02	0.01
35	425	2.72	0.89	0.11	0.05	0.01	0.00	0.00
48	301	3.61	2.12	0.78	0.19	0.06	0.01	0.00
65	212	4.17	3.89	2.06	0.93	0.34	0.10	0.04
100	148	9.33	10.01	6.51	5.09	3.02	1.49	0.73
150	106	15.41	16.62	14.54	10.29	9.99	7.57	4.57
200	75	21.50	15.51	16.27	12.96	17.48	15.47	11.64
270	53	19.58	22.51	21.71	28.59	19.63	21.12	27.87
400	37	7.24	8.94	10.12	10.51	12.14	13.95	10.34
-400	-37	12.79	19.35	27.63	31.26	37.35	40.27	44.79

ELEMENT: ZINC FREQUENCY DISTRIBUTION, PCT

MESH NO	SIZE MICR	FEED	2 MIN	4 MIN	6 MIN	8 MIN	10 MIN	12 MIN
28	598	9.20	2.44	0.85	0.36	0.08	0.06	0.03
35	425	5.33	1.78	0.50	0.13	0.02	0.01	0.00
48	300	8.87	4.52	1.58	0.53	0.15	0.02	0.01
65	212	9.52	8.01	5.10	2.54	0.96	0.35	0.14
100	148	18.03	18.13	15.84	11.68	7.47	4.34	2.40
150	106	20.46	22.66	22.41	19.45	18.32	13.40	13.26
200	75	10.30	13.13	14.30	18.99	17.18	16.33	15.02
270	53	5.53	9.51	11.57	13.36	15.33	18.48	18.22
400	37	2.39	3.76	5.10	6.11	7.58	8.83	9.50
-400	-37	10.43	16.05	22.35	26.85	32.90	38.17	41.40

ELEMENT: IRON FREQUENCY DISTRIBUTION, PCT

MESH NO	SIZE MICR	FEED	2 MIN	4 MIN	6 MIN	8 MIN	10 MIN	12 MIN
28	598	9.20	3.17	1.76	1.05	0.59	0.27	0.17
35	425	4.95	2.68	1.14	0.37	0.16	0.07	0.02
48	301	9.20	5.58	3.76	1.66	0.53	0.22	0.09
65	212	8.49	7.64	6.48	4.24	1.82	0.96	0.45
100	148	18.87	16.18	14.42	11.59	9.28	5.31	3.52
150	106	19.41	25.10	23.77	20.66	19.50	16.59	11.88
200	75	14.20	15.65	16.98	21.50	21.25	20.40	19.49
270	53	5.71	8.27	10.63	13.63	14.79	17.71	19.65
400	37	2.11	3.58	3.67	4.31	6.13	7.98	8.26
-400	-37	7.97	12.35	17.36	20.98	25.96	30.50	36.43

EXPERIMENTAL RESULTS - BATCH GRINDING OF A PB-ZN ORE

MATERIAL: CYCLONE UNDERFLOW

****

FIRST AND R ORDER GRINDING PARAMETERS

MINERAL : OVERALL

****

MESH NO	SIZE MICR	FIRST ORDER K	FIRST ORDER RF	R ORDER P	R ORDER B	R ORDER RP
28	598	0.4247	1.0000	0.7843	0.7106	0.9993
35	425	0.4897	1.0000	0.9282	0.58[illegible]2	1.000[illegible]
48	300	0.4614	0.9998	1.0866	0.3816	1.0000
65	212	0.3412	0.9995	1.0888	0.2757	0.9999
100	148	0.2082	0.9996	1.0715	0.1749	0.9999
150	106	0.1233	0.9998	1.[illegible]485	0.1096	1.0000
200	75	0.[illegible]786	1.0000	1.0264	0.0741	1.0000
270	53	0.1506	0.9957	1.0460	0.0461	0.9956
400	37	0.0385	0.9990	1.0474	0.0153	0.9993

MINERAL : GALENA

****

MESH NO	SIZE MICR	FIRST ORDER K	FIRST ORDER RF	R ORDER P	R ORDER B	R ORDER RP
28	598	0.44[illegible]7	0.9953	0.8926	0.9725	0.9991
35	425	0.5571	0.9934	0.9066	0.74[illegible]7	0.9916
48	300	0.5748	0.9959	1.1136	0.4526	0.9997
65	212	0.443[illegible]	0.9999	1.2392	0.2616	0.9998
100	148	0.2541	0.9951	1.4106	0.1115	0.9923
150	106	0.1757	0.9993	1.626[illegible]	0.0473	0.999[illegible]
200	75	0.1267	0.99[illegible]	1.1145	0.1919	0.9939
270	53	0.[illegible]52[illegible]	0.9752	0.9964	1.[illegible]568	0.9870
400	37	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]

MINERAL :SPHALERITE

MESH NO	SIZE MICR	FIRST ORDER K	RF	P	R ORDER B	RP
28	598	0.4772	0.9984	0.8140	0.7591	0.9957
35	425	0.5388	0.9995	0.9215	0.6549	0.9958
48	300	0.5367	0.9983	1.0460	0.4714	0.9990
65	212	0.3867	0.9979	1.0762	0.3166	0.9989
100	148	0.2169	0.9975	1.0455	0.1809	0.9983
150	106	0.1265	0.9950	1.0886	0.0990	0.9969
200	75	0.0688	0.9991	0.9760	0.0739	0.9995
270	53	0.0448	0.9972	1.0519	0.0410	0.9980
400	37	0.0344	0.9971	1.0486	0.0318	0.9976

MINERAL : PYRITE

MESH NO	SIZE MICR	FIRST ORDER K	RF	P	R ORDER B	RP
28	598	0.2755	0.9993	0.6440	0.6867	0.9995
35	425	0.3530	1.0000	0.8661	0.4826	0.9957
48	300	0.3357	0.9965	0.9809	0.3382	0.9969
65	212	0.2443	0.9937	0.9800	0.2432	0.9942
100	148	0.1584	0.9942	0.9211	0.1816	0.9937
150	106	0.1167	0.9921	1.2335	0.0[illegible]2	0.9965
200	75	0.0556	1.0000	1.0682	0.0477	1.0000
270	53	0.0310	0.99[illegible]	1.0036	0.0316	0.9985
400	37	0.0259	0.9967	1.0495	0.0240	0.9973

MINERAL : CAL/DOL

MESH NO	SIZE MICR	FIRST ORDER K	RF	P	R ORDER B	RP
28	598	0.5265	0.998[illegible]	0.6768	0.6849	0.9972
35	425	0.5849	0.999[illegible]	0.9976	0.5844	0.9999
48	300	0.5412	1.0[illegible]	1.1671	0.3733	0.9999
65	212	0.3987	1.0[illegible]	1.1618	0.2762	0.9999
100	148	0.2144	1.00[illegible]	1.1582	0.1727	0.9997
150	106	0.1338	0.9958	0.9266	0.1633	0.9977
200	75	0.1[illegible]	1.0[illegible]	1.0282	0.0936	1.0[illegible]
270	53	0.07[illegible]3	0.9997	1.0848	0.0575	1.0[illegible]
400	37	[illegible]	1.[illegible]	1.0564	0.044[illegible]	1.0[illegible]

EXPERIMENTAL RESULTS - BATCH GRINDING OF A PB-ZN ORE

MATERIAL: ROD MILL DISCHARGE

WEIGHT RETAINED, GR

MESH NO	SIZE MICR	FEED	1 MIN	2 MIN	4 MIN	8 MIN
28	598	39.71	23.00	14.40	6.87	2.73
35	425	12.73	9.88	6.65	2.40	0.50
48	300	11.87	11.82	10.56	5.70	1.32
65	212	8.87	10.33	10.52	8.04	3.50
100	148	11.63	14.19	15.60	14.78	12.14
150	106	13.11	16.56	18.51	20.58	26.51
200	75	12.71	14.59	17.34	20.48	33.47
270	53	12.76	15.47	17.82	22.37	40.91
400	37	7.29	9.63	11.43	11.88	23.40
-400	-37	32.42	35.21	39.42	49.70	57.51

PERCENT RETAINED

MESH NO	SIZE MICR	FEED	1 MIN	2 MIN	4 MIN	8 MIN
28	598	24.35	14.28	8.88	4.22	1.13
35	425	7.81	6.13	4.10	1.47	0.21
48	300	7.28	7.34	6.51	3.50	0.55
65	212	5.44	6.41	6.48	4.94	1.45
100	148	7.13	8.81	9.61	9.08	5.02
150	106	8.04	10.28	11.41	12.64	10.95
200	75	7.79	9.31	10.69	12.58	13.83
270	53	7.82	9.60	10.98	13.74	16.91
400	37	4.47	5.90	7.04	7.30	9.67
-400	-37	19.88	21.86	24.30	30.53	40.30

OVERALL PB-ZN ORE - CUMULATIVE WT PCT RETAINED

MESH NO	SIZE MICR	FEED	1 MIN	2 MIN	4 MIN	8 MIN
28	598	24.35	14.28	8.88	4.22	1.13
35	425	32.15	20.41	12.97	5.69	1.33
48	300	39.43	27.75	19.48	9.20	1.88
65	212	44.87	34.16	25.97	14.13	3.33
100	148	52.00	42.97	35.58	23.21	8.34
150	106	60.34	53.25	46.99	35.85	19.30
200	75	67.83	62.56	57.68	48.43	33.13
270	53	75.65	72.16	68.66	62.17	50.04
400	37	80.12	78.14	75.70	69.47	59.70

EXPERIMENTAL RESULTS - BATCH GRINDING OF A PB-ZN ORE

MATERIAL: ROD MILL DISCHARGE

ELEMENT: LEAD ASSAYS,PCT

MESH NO	SIZE MICR	FEED	1 MIN	2 MIN	4 MIN	8 MIN
28	598	2.04	1.43	1.10	1.26	0.80
35	425	1.78	1.36	0.92	1.11	0.80
48	300	1.53	1.45	2.80	0.91	0.80
65	212	2.42	1.94	1.54	2.04	1.09
100	148	1.76	2.52	4.23	3.51	2.79
150	106	1.98	2.81	3.08	2.67	2.12
200	75	2.15	1.96	2.01	3.01	2.64
270	53	1.37	1.94	2.55	2.17	2.50
400	37	2.24	1.91	1.39	1.53	1.82
-400	-37	1.13	1.39	1.98	1.53	1.95

ELEMENT: ZINC ASSAYS,PCT

MESH NO	SIZE MICR	FEED	1 MIN	2 MIN	4 MIN	8 MIN
28	598	8.86	6.19	6.14	5.30	3.25
35	425	7.48	6.58	6.08	5.56	4.07
48	300	6.71	6.68	7.74	5.12	4.57
65	212	7.68	8.02	5.35	6.64	4.63
100	148	6.06	6.67	7.30	7.00	6.92
150	106	5.99	6.81	6.54	6.66	6.75
200	75	5.68	5.85	5.09	7.84	6.18
270	53	5.33	5.29	6.20	6.46	6.28
400	37	5.53	6.58	5.79	6.06	6.42
-400	-37	6.76	6.68	6.76	6.85	7.16

ELEMENT: IRON ASSAYS,PCT

MESH NO	SIZE MICR	FEED	1 MIN	2 MIN	4 MIN	8 MIN
28	598	12.70	14.91	17.95	19.49	18.02
35	425	11.29	10.93	12.63	18.91	26.73
48	300	8.35	9.75	12.38	13.52	20.15
65	212	8.54	8.02	8.04	12.10	17.77
100	148	5.10	5.82	8.55	8.47	12.22
150	106	4.45	6.42	5.25	6.46	8.27
200	75	5.14	5.52	5.43	7.33	8.55
270	53	5.72	5.61	5.86	6.95	9.13
400	37	5.35	5.75	5.24	5.73	6.48
-400	-37	7.02	7.09	7.34	7.24	8.50

EXPERIMENTAL RESULTS - BATCH GRINDING OF A FE-ZN ORE

MATERIAL: ROD MILL DISCHARGE

ELEMENT: LEAD FREQUENCY DISTRIBUTION, PCT

MESH NO	SIZE MICR	FEED	1 MIN	2 MIN	4 MIN	6 MIN
28	598	28.18	11.24	4.34	2.38	0.42
35	425	7.88	4.59	1.68	0.73	0.08
48	300	6.32	5.86	8.10	1.42	0.20
65	212	7.47	6.85	4.44	4.51	0.73
100	148	7.12	12.22	18.08	14.25	6.50
150	106	9.03	15.91	15.62	15.09	10.79
200	75	9.51	10.04	9.55	16.93	16.96
270	53	6.08	10.26	12.45	13.34	19.63
400	37	5.68	6.29	4.35	4.99	8.18
-400	-37	12.74	16.73	21.39	26.35	36.50

ELEMENT: ZINC FREQUENCY DISTRIBUTION, PCT

MESH NO	SIZE MICR	FEED	1 MIN	2 MIN	4 MIN	6 MIN
28	598	30.72	13.63	8.56	3.34	0.55
35	425	8.31	6.22	3.91	1.22	0.13
48	300	6.95	7.56	7.91	2.68	0.38
65	212	6.10	7.93	5.45	4.90	1.01
100	148	6.15	9.06	11.02	9.49	5.22
150	106	6.66	10.79	11.72	12.57	11.13
200	75	6.30	8.39	8.54	14.73	12.86
270	53	5.94	7.83	10.69	13.25	15.97
400	37	3.52	6.07	6.41	6.60	9.34
-400	-37	19.14	22.51	25.79	31.22	43.41

ELEMENT: IRON FREQUENCY DISTRIBUTION, PCT

MESH NO	SIZE MICR	FEED	1 MIN	2 MIN	4 MIN	6 MIN
28	598	37.50	26.13	19.35	9.95	2.28
35	425	10.69	8.23	6.29	3.37	0.62
48	300	7.37	8.78	9.78	5.73	1.23
65	212	5.63	6.31	6.33	7.23	2.88
100	148	4.41	6.29	9.98	9.31	6.87
150	106	4.29	8.16	7.27	9.88	10.15
200	75	4.66	6.30	7.05	11.16	13.25
270	53	5.43	6.61	7.82	11.56	17.30
400	37	2.90	4.22	4.48	5.06	7.02
-400	-37	16.92	19.12	21.65	26.75	38.39

EXPERIMENTAL RESULTS - BATCH GRINDING OF A PB-ZN ORE

MATERIAL: ROD MILL DISCHARGE

FIRST AND P ORDER GRINDING PARAMETERS

MINERAL : OVERALL
****

MESH NO	SIZE MICR	FIRST ORDER K	FIRST ORDER RF	P ORDER P	P ORDER B	P ORDER RP
28	598	0.4114	0.9980	0.8578	0.5413	0.9991
35	425	0.4236	0.9997	0.9649	0.4579	0.9958
48	300	0.3692	0.9959	1.0256	0.3496	0.9999
65	212	0.2956	0.9997	1.0417	0.2703	0.9958
100	148	0.2065	0.9996	1.0434	0.1886	0.9996
150	106	0.1323	0.9998	1.0521	0.1193	0.9999
200	75	0.0856	0.9998	1.0290	0.0804	0.9959
270	53	0.0457	1.0000	1.0273	0.0473	1.0000
400	37	0.0357	0.9975	1.2551	0.0246	0.9994

MINERAL : GALENA
****

MESH NO	SIZE MICR	FIRST ORDER K	FIRST ORDER RF	P ORDER P	P ORDER B	P ORDER RP
28	598	0.4868	0.9494	0.7141	0.5873	0.9697
35	425	0.5122	0.9557	0.7872	0.8890	0.9712
48	300	0.5284	0.9979	0.8655	0.6460	0.9948
65	212	0.3799	0.9999	0.8075	0.5597	0.9999
100	148	0.1923	0.9884	0.7095	0.3114	0.9697
150	106	0.1334	0.9909	0.9162	0.1420	0.9827
200	75	0.0615	0.9964	0.6657	0.1244	0.9997
270	53	0.0383	0.9998	0.7862	0.0508	0.9978
400	37	0.0357	0.9882	0.9288	0.0493	0.9901

MINERAL : SPHALERITE
****

MESH NO	SIZE MICR	FIRST ORDER K	FIRST ORDER RF	P	P ORDER B	RP
28	598	0.4690	1.0000	0.7245	0.7995	0.9984
35	425	0.4919	0.9998	0.8332	0.6641	0.9985
48	300	0.4543	0.9928	0.9184	0.4867	0.9864
65	212	0.3593	0.9990	0.9543	0.3792	0.9982
100	148	0.2436	0.9967	0.9340	0.2604	0.9939
150	106	0.1619	0.9974	0.9817	0.1593	0.9959
200	75	0.0860	0.9963	0.8527	0.1185	0.9980
270	53	0.0458	0.9989	0.7271	0.0796	1.0000
400	37	0.0395	0.9995	0.9619	0.0431	0.9996

MINERAL : PYRITE
****

MESH NO	SIZE MICR	FIRST ORDER K	FIRST ORDER RF	P	P ORDER B	RP
28	598	0.3232	0.9957	0.9381	0.3560	0.9992
35	425	0.3173	0.9996	0.9629	0.3334	0.9993
48	300	0.2777	0.9950	1.0402	0.2411	0.9934
65	212	0.2136	0.9974	0.9939	0.2058	0.9962
100	148	0.1549	0.9843	0.9543	0.1482	0.9707
150	106	0.1155	0.9940	1.1237	0.0860	0.9937
200	75	0.0721	0.9984	1.0635	0.0621	0.9985
270	53	0.0395	1.0000	0.9473	0.0432	0.9998
400	37	0.0335	1.0000	1.1497	0.0259	0.9997

MINERAL : CAL/DCL
****

MESH NO	SIZE MICR	FIRST ORDER K	FIRST ORDER RF	P	P ORDER E	RP
28	599	0.4443	0.9942	0.8921	0.5751	0.9958
35	425	0.4821	0.9994	1.0338	0.4649	0.9990
48	300	0.4044	0.9994	1.0770	0.3617	0.9987
65	212	0.3245	0.9999	1.1082	0.2666	1.0000
100	149	0.2223	0.9997	1.1138	0.1856	0.9989
150	106	0.1336	0.9998	1.0568	0.1227	0.9994
200	75	0.0936	0.9997	1.0722	0.0786	0.9999
270	53	0.0535	1.0000	1.1194	0.0435	0.9998
400	37	0.0415	0.9944	1.3670	0.0219	0.9981

IV.2 Program to Adjust the Plant Data

```
C
C
C     PROGRAM TO ADJUST THE SIZE AND CHEMICAL
C     ASSAYS IN A CLOSED CIRCUIT OF GRINDING
C
C     THE ADJUSTMENTE IS BASED ON MINIMIZATION
C     OF SUM OF SQUARES OF RESIDUAL ERRORS
C
C     TO SOLVE THE DIFFERENTIAL EQUATIONS APPEARING
C     IN THIS ANALYSIS, THE METHOD OF THE LAGRANGIAN
C     MULTIPLIERS IS UTILIZED
C
C     NOMENCLATURE
C     ------------
C
C     INDICES
C     -------
C          I     DENOTES TYLER SCREEN NUMBER (1 IS THE
C                COARSEST)
C          I1    MAXIMUM NUMBER OF SCREENS
C          J     NUMBER OF STREAMS (= 5)
C          K     NUMBER OF ELEMENT ASSAYS
C                1 IS PB; 2 IS ZN; 3 IS FE
C          K1    MAXIMUM NUMBER OF ELEMENT ASSAYS
C                (INPUT DATA)
C          K2    DENOTES CALCITE-DOLOMITE ASSAYS
C                (CALCULATED BY THE PROGRAM)
C          N     NUMBER OF NODES
C                1 IS SUMP; 2 IS CYCLONE; 3 IS BALL MILL;
C                4 IS ENTIRE CIRCUIT
C
C     ALPHA             OVERALL ADJUSTED CIRCULATING LOAD
C                       MEASURED ON THE CYCLONE FEED STREAM
C     ALPHAM            AS ABOVE BUT MEASURED ON THE CYCLONE
C                       UNDERFLOW STREAM
C     ALPHM(K)          MINERAL CIRCULATING LOAD MEASURED
C                       ON THE CYCLONE FEED STREAM
C     A1(I,J)           SIZE ASSAYS  IN STREAM 1  (PERCENT)
C     CHEM(I,J,K)       ELEMENT ASSAYS IN STREAM 1  (PERCENT)
C     STEIOM(K)         STEICHIOMETRIC FACTOR FOR CONVERTING
C                       ELEMENT ASSAYS TO MINERAL ASSAYS
C     MESH(I)           TYLER MESH NUMBER
C     ELEM(K)           STRING MATRIX
C
C     UNADJUSTED PARAMETERS
C     ---------------------
C
C     UNITM(I,J,K)      ELEMENT UNITS
C     UNITMM(I,J,K)     MINERAL UNITSS
C     CUMU(I,J,K)       CUMULATIVE ELEMENT UNITS COARSER
C     CUMMU(I,J,K)      CUMULATIVE MINERAL UNITS COARSER
C     SUMM(I,J)         CUMULATIVE SULPHIDE MINERALS
C                       ON EACH SIZE FRACTION
C
C     ADJUSTED PARAMETERS
C     -------------------
C
C     UNIT(I,J,K)       MINERAL UNITS
C     S(I,J)            CUMULATIVE SULPHIDE MINERAL UNITS
```

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```
C                       ON EACH SIZE FRACTION
C      CUM(I,J,K)       CUMULATIVE ELEMENT UNITS COARASER
C      AVG(J,K)         OVERALL ELEMENT ASSAYS
C      DELTM(N,K)       MINERAL FLOW RATE RESIDUAL ERROR
C                       MEASURED IN NODES 1 TO 4
C      A(I,J)           COEFICIENTS IN THE SYSTEM OF
C                       SIMULTANEOUS EQUATIONS
C      B(I)             RIGHT-HAND SIDE TERM OF THE ABOVE
C                       SYSTEM
C      X(I)             THE UNKNOWN PARAMETERS OF ABOVE
C      R(I)             THE ADJUSTING TERM IN THE
C                       OVERALL ELEMENT ASSAYS
C      NOTE:
C      -----
C      CHEM(I,J,K)  TAKES ON THE ADJUSTED ELEMENT ASSAYS
C      ONCE THE ADJUSTMENT ANALYSIS HAS BEEN PERFORMED
C
C
C      SUBROUTINE ADJUST
C      -----------------
C      USAGE:     TO COMPUTE THE ADJUSTED CIRCULATING
C                 LOADS (OVERALL AND MINERAL-BY-MINERAL)
C                 AND TO ADJUST THE SIZE ASSAYS
C
C      INPUT ARGUMENTS        ARGUMENTS IN CALLING PROGRAM
C      ---------------        ----------------------------
C          IN                            I1
C          A                             A1
C      OUTPUT ARGUMENTS
C      ----------------
C          ALPHA                         ALPHA
C          ALPHAM                        ALPHAM
C          X                             X1
C          ADJ                           ADJ
C
C      SUBROUTINE ADJAS
C      ----------------
C      USAGE:     TO ADJUST THE MINERAL FREQUENCY
C                 DISTRIBUTION OF EACH STREAM
C
C      INPUT ARGUMENTS        ARGUMENTS IN CALLING PROGRAM
C      ---------------        ----------------------------
C          IN                            I1.
C          A                             FD
C          ALPHA                         ALPH
C      OUTPUT ARGUMENTS
C      ----------------
C          ADJ                           ADFD


C      NOMENCLATURE
C      ------------
C
C      DELT1(I)         RESIDUAL ERROR IN NODE 1 (SUMP)
C      DELT2(I)         RESIDUAL ERROR IN NODE 2 (CYCLONE)
C      LAMD1(I)         LAGRANGIAN MULTIPLIER (NODE 1)
C      LAMD2(I)         LAGRANGIAN MULTIPLIER (NODE 2)
```

CONTINUED ......

```
C       DELTA(I,J)        ADJUSTING PARAMETER
C       ADJ(I,J)          ADJUSTED SIZE ASSAYS
C


C       NOMENCLATURE
C       ------------
C       DELT1(I)          RESIDUAL ERROR IN NODE 1 (SUMP)
C       DELT2(I)          RESIDUAL ERROR IN NODE 2 (SUMP)
C       LAMD1(I)          LAGRANGIAN MULTIPLIER (NODE 1)
C       LAMD2(I)          LAGRANGIAN MULTIPLIER (NODE 2)
C       DELTA(I,J)        ADJUSTING PARAMETER
C       ADJ(I,J)          ADJUSTED MINERAL FREQUENCY
C                         DISTRIBUTION
      CHARACTER*7 ELEM(4)
      DIMENSION A1(20,5),CHEM(20,5,4),MESH(20),ADJ(20,5),UNIT(20,5,4)
      DIMENSION S(20,5),CUM(20,5,4),AVG(5,4),DELTM(4,4)
      DIMENSION ADJ2(5,4),ALPHM(4),ADJ3(20,5,4)
      DIMENSION CHEM1(20,5,4),DELTA(5,4)
      DIMENSION V1M(5),V2M(5),ADJUN(20,5,4),SUMM(20,5)
      DIMENSION STEIOM(3),ADFD(20,5),FD(20,5),FD1(20,5,4)
      DIMENSION UNITM(20,5,4),UNITMM(20,5,4),CUMU(20,5,4),CUMMU(20,5,4)
      DIMENSION A(4,4)
      DIMENSION B(4),X(4)
      DIMENSION R(5)
      DIMENSION Y(10,4),YA(10,4)
      READ(5,1)I1,J1,K1
      K2= K1 + 1
      READ(5,2)((A1(I,J),I=1,I1),J=1,5)
      READ(5,2)(((CHEM(I,J,K),I=1,I1),J=1,5),K=1,K1)
      READ(5,3)(STEIOM(I),I=1,K1)
      READ(5,4)(MESH(I),I=1,I1),N
      READ(5,5)(ELEM(I),I=1,K2)
    1 FORMAT(3I2)
    2 FORMAT(10F5.2)
    3 FORMAT(3F5.2)
    4 FORMAT(I1I4)
    5 FORMAT(4A7)
C
C    FINDING THE BEST ESTIMATE OF RATIONALIZED FLOW RATES (OVERALL)
C
C    ALSO, ADJUSTING THE SCREEN ASSAYS IN ALL STREAMS
C    BOTH COMPUTATIONS MAKE USE OF SUBROUTINE ADJUST
C
      CALL ADJUST(I1,A1,ALPHA,ALPHAM,X1,ADJ)
C
C     OVERALL ASSAYS ADJUSTMENT
C     SECTION 1 - FINDING THE UNADJUSTED MINERAL COMPOSITION
C     AND MINERAL UNITS
C
      DO 10 K=1,K1
      DO 10 J=1,J1
      SUM1= 0.0
      SUM2= 0.0
      DO 10 I=1,I1
      UNITM(I,J,K)= A1(I,J)*CHEM(I,J,K)
      UNITMM(I,J,K)= A1(I,J)*CHEM(I,J,K)*STEIOM(K)
```

CONTINUED ......

```
      CUMU(I,J,K)= SUM1 + UNITM(I,J,K)
      CUMMU(I,J,K)= SUM2 + UNITMM(I,J,K)
      SUM1= CUMU(I,J,K)
      SUM2= CUMMU(I,J,K)
   10 CONTINUE
      DO 20 J=1,J1
      DO 20 I=1,I1
      SUM1= 0.0
      DO 20 K=1,K1
      SUMM(I,J)= SUM1 + UNITMM(I,J,K)
      SUM1= SUMM(I,J)
   20 CONTINUE
      DO 30 J=1,J1
      DO 30 I=1,I1
      UNITMM(I,J,4)= 100.*A1(I,J) - SUMM(I,J)
   30 CONTINUE
      DO 35 J=1,J1
      DO 35 I=1,I1
      CHEM(I,J,4)= UNITMM(I,J,4)/A1(I,J)
   35 CONTINUE
      DO 36 J=1,J1
      SUM1= 0.0
      DO 36 I=1,I1
      CUMU(I,J,4)= SUM1 + UNITMM(I,J,4)
      SUM1= CUMU(I,J,4)
   36 CONTINUE
      DO 40 K=1,K1
      DO 40 J=1,5
      DO 40 I=1,I1
      UNIT(I,J,K)= ADJ(I,J)*CHEM(I,J,K)*STEIQM(K)
   40 CONTINUE
C
C     SECTION 2 - FINDING THE CALCITE/DOLOMITE UNITS
C
      DO 50 J=1,5
      DO 50 I=1,I1
      SUM1= 0.0
      DO 50 K=1,K1
      S(I,J)= SUM1 + UNIT(I,J,K)
      SUM1= S(I,J)
   50 CONTINUE
      DO 60 J=1,5
      DO 60 I=1,I1
      UNIT(I,J,4)= 100.*ADJ(I,J) - S(I,J)
   60 CONTINUE
C
C     SECTION 2 - FINDING THE OVERALL MINERAL UNITS
C
      DO 70 K=1,K2
      DO 70 J=1,5
      SUM1= 0.0
      DO 70 I=1,I1
      CUM(I,J,K)= SUM1 + UNIT(I,J,K)
      SUM1= CUM(I,J,K)
   70 CONTINUE
C
C     SECTION 4 - FINDING THE OVERALL ELEMENT ASSAYS (PERCENT)
C
```

CONTINUED ......

```
      DO 80 K=1,K2
      DO 80 J=1,J1
      AVG(J,K)= CUMU(10,J,K)/100.
   80 CONTINUE
      DO 90 K=1,K2
      DELTM(1,K)= ALPHAM*AVG(5,K) + AVG(1,K) - ALPHA*AVG(2,K)
      DELTM(2,K)=  ALPHAM*AVG(4,K) + AVG(3,K) - ALPHA*AVG(2,K)
      DELTM(3,K)=   AVG(5,K) - AVG(4,K)
      DELTM(4,K)=  AVG(3,K) - AVG(1,K)
   90 CONTINUE
C
C    FINDING THE OVERALL MINERAL ASSAYS (PERCENT)
C    THIS IS AN ADJUSTMENT ANALYSIS
C
C
C     SECTION 2 - SOLVING THE SIMULTANEOUS SYSTEM OF EQUATIONS
C
      N= 4
      DO 100 L1=1,K2
C
C     SECTION 1 - FINDING THE COEFFICIENTS OF THE SIMULTANEOUS EQUATION
C
      A(1,1)= X1
      A(1,2)= ALPHA**2
      A(1,3)= ALPHAM
      A(1,4)= -1.
      A(2,1)= ALPHA**2
      A(2,2)= X1
      A(2,3)= -ALPHAM
      A(2,4)= 1.
      A(3,1)= ALPHAM
      A(3,2)= -ALPHAM
      A(3,3)= 2.
      A(3,4)= 0.0
      A(4,1)= -1.
      A(4,2)= 1.0
      A(4,3)= 0.0
      A(4,4)= 2.0
      DO 101 I=1,4
      B(I)= DELTM(I,L1)
  101 CONTINUE
      NM1= N - 1
      DO 600 K=1,NM1
      KP1= K + 1
      L= K
      DO 400 I=KP1,N
      IF(ABS(A(I,K)).GT.ABS(A(L,K)))L=I
  400 CONTINUE
      IF(L.EQ.K)GO TO 300
      DO 410 J=K,N
      TEMP= A(K,J)
      A(K,J)= A(L,J)
  410 A(L,J)= TEMP
      TEMP= B(K)
      B(K)= B(L)
      B(L)= TEMP
  300 DO 590 I=KP1,N
      FACTOR= A(I,K)/A(K,K)
```

CONTINUED ......

```
      DO 500 J=KP1,N
  500 A(I,J)= A(I,J) - FACTOR*A(K,J)
  590 B(I)= B(I) - FACTOR*B(K)
  600 CONTINUE
      X(N)= B(N)/A(N,N)
      I= NM1
  800 IP1= I + 1
      SUM= 0.0
      DO 900 J=IP1,N
      SUM= SUM + A(I,J)*X(J)
  900 CONTINUE
      X(I)= (B(I) - SUM)/A(I,I)
      I= I - 1
      IF(I.GE.1)GO TO 800
      R(1)= X(1) - X(4)
      R(2)= -ALPHA*(X(1) + X(2))
      R(3)= X(2) + X(4)
      R(4)= ALPHAM*X(2) - X(3)
      R(5)= ALPHAM*X(1) + X(3)
      DO 102 J=1,5
      ADJ2(J,L1)= AVG(J,L1) - R(J)
  102 CONTINUE
  100 CONTINUE
C
C     FINDING THE CIRCULATING LOAD OF EACH MINERAL COMPONENT
C
      DO 130 I=1,K2
      ALPHM(I)= ADJ2(4,I)/ADJ2(3,I)*ALPHAM + 1.
  130 CONTINUE
C
C     FINDING THE MINERAL FREQUENCY DISTRIBUTION
C
      DO 140 K=1,K1
      DO 140 J=1,5
      DO 140 I=1,I1
      FD1(I,J,K)= UNIT(I,J,K)/CUM(10,J,K)
  140 CONTINUE
      DO 145 J=1,5
      DO 145 I=1,I1
      FD1(I,J,4)= UNIT(I,J,4)/AVG(J,4)/100.
  145 CONTINUE
C
C     ADJUSTING THE ABOVE MINERAL FREQUENCY DISTRIBUTION
C
      DO 150 K=1,K2
      ALPH= ALPHM(K)
      DO 151 J=1,5
      DO 151 I=1,I1
      FD(I,J)= FD1(I,J,K)
  151 CONTINUE
      CALL ADJAS(I1,FD,ALPH,ADFD)
      DO 152 J=1,5
      DO 152 I=1,I1
      ADJ3(I,J,K)= ADFD(I,J)
  152 CONTINUE
  150 CONTINUE
C
C     FINDING THE ADJUSTED ELEMENT COMPOSITION
```

CONTINUED ......

```
C      CALCITE/DOLOMITE IS GIVEN IN PERCENT
C
       DO 160 K=1,K2
       DO 160 J=1,5
       DO 160 I=1,I1
       ADJUN(I,J,K)= ADJ3(I,J,K)*ADJ2(J,K)*100.
       CHEM1(I,J,K)= ADJUN(I,J,K)/ADJ(I,J)
  160  CONTINUE
       WRITE(6,200)
       WRITE(6,210)
       DO 190 I=1,I1
       WRITE(6,220)MESH(I),(A1(I,J),J=1,5),(ADJ(I,J),J=1,5)
  190  CONTINUE
       WRITE(6,240)ALPHA
       DO 195 K=1,K2
       WRITE(6,230)ELEM(K)
       WRITE(6,210)
       DO 196 I=1,I1
       WRITE(6,220)MESH(I),(CHEM(I,J,K),J=1,5),(CHEM1(I,J,K),J=1,5)
  196  CONTINUE
       WRITE(6,245)(AVG(I,K),I=1,5),(ADJ2(I,K),I=1,5)
       WRITE(6,240)ALPHM(K)
  195  CONTINUE
  200  FORMAT('1'////' ',36X,'SIZE ASSAYS ADJUSTMENT - RESULTS'////)
  210  FORMAT(' ',15X,'MESH',11X,'UNADJUSTED DATA',17X,'ADJUSTED DATA'/'
      @',16X,'NO',6X,'RMD',4X,'CF',3X,'COF',3X,'CUF',3X,'BMD',5X,
      @'RMD',4X,'CF',3X,'COF',3X,'CUF',3X,'BMD'//)
  220  FORMAT(' ',15X,I4,4X,5(F5.2,1X),2X,5(F5.2,1X)//)
  230  FORMAT('1'////' ',34X,'CHEMICAL ASSAYS ADJUSTMENT - RESULTS'//' ',
      @34X,'ELEMENT:',A7////)
  245  FORMAT(/' ',12X,'AVERAGE',4X,5(F5.2,1X),2X,5(F5.2,1X)///)
  240  FORMAT(' ',36X,'ALPHA:',11X,F6.2)
C
C     FINDING THE UNADJUSTED AND ADJUSTED
C     CYCLONE SELECTIVITY INDEXES
C
       DO 170 K=1,K2
       DO 170 I=1,I1
       Y(I,K)= CHEM(I,4,K)*A1(I,4)/(CHEM(I,4,K)*A1(I,4) +
      @        CHEM(I,3,K)*A1(I,3)/ALPHAM)
       YA(I,K)= CHEM1(I,4,K)*ADJ(I,4)/(CHEM1(I,4,K)*ADJ(I,4) +
      @        CHEM1(I,3,K)*ADJ(I,3)/ALPHAM)
  170  CONTINUE
       WRITE(6,250)(ELEM(K),K=1,K2),(ELEM(K),K=1,K2)
       DO 198 I=1,I1
       WRITE(6,255)MESH(I),(Y(I,K),K=1,K2),(YA(I,K),K=1,K2)
  198  CONTINUE
  250  FORMAT('1'////' ',34X,'CYCLONE SELECTIVITY CURVES'////' ',
      @15X,'MESH',3X,'UNADJUSTED SELECTIVITY INDEX   ADJUSTED SELECTIVITY
      @ INDEX'/' ',16X,'NO',1X,3A7,2X,A7,3X,3A7,2X,A7//)
  255  FORMAT(' ',15X,I4,3X,4(F6.4,1X),4X,4(F6.4,1X)//)
       STOP
       END
       SUBROUTINE ADJUST(IN,A,ALPHA,ALPHAM,X,ADJ)
       DIMENSION A(20,5),ADJ(20,5)
       DIMENSION DELT1(20),DELT2(20),DELTA(20,5)
       REAL LAMD1(20),LAMD2(20)
       FL= FLOAT(IN) -1.
```

CONTINUED ......

```
      S5= 0.0
      S6= 0.
      S7= 0.
      S8= 0.
      DO 10 I=1,IN
      S1= A(I,2) - A(I,5)
      S2= A(I,5) - A(I,1)
      S3= A(I,2) - A(I,4)
      S4= A(I,4) - A (I,3)
      S5= S1*S2 + S5
      S6= S3*S4 + S6
      S7= S1**2 + S7
      S8= S3**2 + S8
   10 CONTINUE
      A1= S5 + S6
      A2= S7 + S8
      ALPHA= -A1/A2
      ALPHAM= ALPHA - 1.
      X= ALPHA**2 + ALPHAM**2 + 1.
      Y= ALPHA**2/X
      Z= ALPHA**4/X
      DO 20 I=1,IN
      DELT1(I)= ALPHA*(A(I,2) - A(I,5)) + (A(I,5) - A(I,1))
      DELT2(I)= ALPHA*(A(I,2) - A(I,4)) + (A(I,4) - A(I,3))
      LAMD1(I)= (DELT1(I) - Y*DELT2(I))/(X - Z)
      LAMD2(I)= (DELT2(I) - LAMD1(I)*ALPHA**2)/X
      DELTA(I,1)= LAMD1(I)
      DELTA(I,2)= -ALPHA*(LAMD1(I) + LAMD2(I))
      DELTA(I,3)= LAMD2(I)
      DELTA(I,4)= ALPHAM*LAMD2(I)
      DELTA(I,5)= ALPHAM*LAMD1(I)
   20 CONTINUE
      DO 30 J=1,5
      DO 30 I=1,IN
      ADJ(I,J)= A(I,J) + DELTA(I,J)
   30 CONTINUE
      RETURN
      END
      SUBROUTINE ADJAS(IN,A,ALPHA,ADJ)
      DIMENSION A(20,5),ADJ(20,5)
      DIMENSION DELT1(20),DELT2(20),DELTA(20,5)
      REAL LAMD1(20),LAMD2(20)
      FL= FLOAT(IN) - 1.
      ALPHAM= ALPHA - 1.
      X= ALPHA**2 + ALPHAM**2 + 1.
      Y= ALPHA**2/X
      Z= ALPHA**4/X
      DO 20 I=1,IN
      DELT1(I)= ALPHA*(A(I,2) - A(I,5)) + (A(I,5) - A(I,1))
      DELT2(I)= ALPHA*(A(I,2) - A(I,4)) + (A(I,4) - A(I,3))
      LAMD1(I)= (DELT1(I) - Y*DELT2(I))/(X - Z)
      LAMD2(I)= (DELT2(I) - LAMD1(I)*ALPHA**2)/X
      DELTA(I,1)= LAMD1(I)
      DELTA(I,2)= -ALPHA*(LAMD1(I) + LAMD2(I))
      DELTA(I,3)= LAMD2(I)
      DELTA(I,4)= ALPHAM*LAMD2(I)
      DELTA(I,5)= ALPHAM*LAMD1(I)
   20 CONTINUE
```

CONTINUED ......

```
      DO 30 J=1,5
      DO 30 I=1,IN
      ADJ(I,J)= A(I,J) + DELTA(I,J)
   30 CONTINUE
      RETURN
      END
$DATA
C
C ... DATA CARDS
$
```

SIZE ASSAYS ADJUSTMENT - RESULTS

MESH NO	UNADJUSTED DATA RMD	CF	COF	CUF	BMD	ADJUSTED DATA RMD	CF	COF	CUF	BMD
28	19.86	7.69	0.01	12.84	2.16	19.42	8.27	0.23	13.20	1.44
35	8.23	4.69	0.34	7.18	3.39	7.96	4.86	0.54	7.51	2.96
48	7.67	6.68	0.70	9.96	6.84	7.39	6.77	0.94	10.35	6.39
65	5.92	7.03	2.61	9.32	8.18	5.72	7.04	2.81	9.64	7.85
100	7.69	11.29	7.63	13.60	13.80	7.62	11.38	7.67	13.66	13.69
150	8.82	13.62	13.55	14.91	16.52	9.05	13.91	13.21	14.35	16.90
200	8.22	11.39	11.52	10.42	13.00	8.15	11.09	11.70	10.71	12.89
270	8.46	9.81	15.00	7.19	10.26	8.66	9.86	14.78	6.83	10.59
400	5.31	5.65	9.37	3.32	5.58	5.38	5.57	9.33	3.26	5.69
-400	19.84	22.15	39.27	11.26	20.27	20.66	21.25	38.79	10.48	21.61

ALPHA: 2.63

CHEMICAL ASSAYS ADJUSTMENT - RESULTS,

ELEMENT: LEAD

MESH NO	RMD	UNADJUSTED DATA CF	COF	CUF	BMD	RMD	ADJUSTED DATA CF	COF	CUF	BMD
28	1.42	0.96	1.34	1.24	2.88	1.48	1.33	1.41	1.32	0.04
35	1.20	0.70	1.34	0.92	1.41	1.25	1.02	1.30	1.00	0.64
48	2.06	1.23	0.11	2.27	1.24	2.17	1.73	-0.16	1.84	1.42
65	1.31	1.35	0.09	4.18	2.82	1.40	2.55	-0.12	3.02	3.06
100	2.85	2.19	0.29	4.38	4.05	2.94	3.19	0.25	4.21	3.28
150	1.53	3.63	0.20	5.10	5.40	1.66	3.83	0.22	5.87	4.59
200	1.36	7.20	0.38	13.22	11.70	1.39	8.14	0.35	13.36	10.76
270	1.43	10.96	1.05	18.34	11.94	1.59	9.21	1.02	20.07	13.03
400	1.56	7.75	2.39	11.94	10.05	1.64	6.77	2.29	14.64	9.75
-400	1.49	3.76	3.29	4.83	4.28	1.69	3.55	3.09	4.59	4.70
AVERAGE	1.55	4.19	1.77	5.83	6.05	1.66	4.29	1.66	5.91	5.91

ALPHA: 6.81

CHEMICAL ASSAYS ADJUSTMENT - RESULTS

ELEMENT: ZINC

MESH NO	UNADJUSTED DATA RMD	CF	COF	CUF	BMD	ADJUSTED DATA RMD	CF	COF	CUF	BMD
28	4.44	5.90	1.66	4.91	9.46	4.95	5.36	5.51	5.36	8.48
35	5.47	5.06	1.66	5.70	7.28	6.00	5.86	1.89	6.03	5.62
48	6.53	7.08	0.76	8.12	6.97	7.48	7.39	-1.22	7.87	7.32
65	4.16	7.86	0.60	6.78	5.24	5.18	6.00	0.47	6.99	6.36
100	7.40	10.50	1.60	12.96	10.88	8.43	10.22	1.35	13.28	10.84
150	4.73	10.90	4.96	10.72	11.41	5.21	9.55	4.89	12.18	10.97
200	4.48	6.66	6.45	7.98	8.13	5.00	7.07	5.83	7.90	7.87
270	5.17	5.83	6.56	6.10	7.82	5.53	6.39	6.10	6.78	6.83
400	4.96	6.77	6.62	7.41	7.18	5.62	6.58	6.08	7.47	7.14
-400	5.26	7.58	8.19	7.12	8.04	6.00	7.33	7.51	6.92	8.11
AVERAGE	5.18	7.78	6.38	8.16	8.63	5.84	7.48	5.84	8.49	8.49

ALPHA: 3.37

CHEMICAL ASSAYS ADJUSTMENT - RESULTS

ELEMENT: IRON

MESH NO	UNADJUSTED DATA RMD	CF	COF	CUF	BMD	ADJUSTED DATA RMD	CF	COF	CUF	BMD
28	9.80	9.74	18.29	11.60	15.42	10.23	11.13	10.52	11.13	18.60
35	6.84	6.35	18.29	7.22	15.86	6.94	8.41	17.74	8.00	10.85
48	7.95	9.40	4.86	12.91	13.87	8.34	11.50	2.62	11.99	13.74
65	5.46	11.54	3.19	11.79	11.59	5.96	10.60	2.83	11.99	12.68
100	6.28	13.36	6.49	17.91	16.80	6.78	14.26	4.86	17.49	16.82
150	4.23	17.11	2.17	21.30	20.98	4.45	16.07	2.22	23.90	19.89
200	3.78	12.91	5.72	20.15	18.17	4.07	13.94	5.20	19.80	17.78
270	4.88	9.77	7.14	15.38	23.13	4.40	12.63	6.87	20.27	16.76
400	4.33	8.31	7.17	9.59	11.89	4.48	8.41	6.74	11.35	10.71
-400	5.58	9.89	9.48	10.03	11.81	5.87	9.52	8.85	11.04	11.66
AVERAGE	6.36	11.41	7.02	14.66	16.34	6.56	12.00	6.58	15.32	15.32

ALPHA: 4.80

SIZE ASSAYS ADJUSTMENT - RESULTS

MESH NO	UNADJUSTED DATA RMD	CF	COF	CUF	BMD	ADJUSTED DATA RMD	CF	COF	CUF	BMD
28	24.35	11.22	0.08	14.70	3.75	24.24	10.44	0.45	15.43	3.54
35	5.97	4.84	0.16	6.55	4.00	5.94	4.60	0.27	6.77	3.94
48	6.34	7.11	1.81	9.59	7.50	6.31	7.07	1.85	9.67	7.44
65	6.09	7.72	4.61	8.98	8.31	6.10	7.58	4.65	9.05	8.33
100	10.21	12.75	11.40	14.13	14.51	10.20	13.06	11.31	13.94	14.49
150	10.11	13.71	16.11	13.39	15.19	10.33	13.86	15.85	12.86	15.62
200	7.99	10.30	12.94	9.05	10.98	8.12	10.19	12.85	8.87	11.23
270	7.42	8.47	12.82	6.68	9.05	7.47	8.58	12.74	6.51	9.14
400	3.70	4.35	7.96	3.20	4.33	3.89	4.43	7.75	2.77	4.70
-400	17.82	19.53	32.11	13.71	22.38	17.41	20.17	32.31	14.11	21.55

ALPHA: 3.00

CHEMICAL ASSAYS ADJUSTMENT - RESULTS

ELEMENT: LEAD

MESH NO	UNADJUSTED DATA RMD	CF	COF	CUF	BMD	ADJUSTED DATA RMD	CF	COF	CUF	BMD
28	1.36	1.46	0.29	2.23	1.33	1.44	1.75	-0.09	1.78	2.83
35	2.21	1.70	0.29	1.77	1.76	2.32	1.86	-0.29	1.89	1.50
48	2.63	1.35	0.12	0.70	1.46	2.75	1.29	0.17	1.40	0.68
65	0.40	2.00	0.09	5.61	4.41	0.43	3.37	0.02	4.24	4.45
100	1.44	5.20	0.15	10.12	5.18	1.58	5.69	0.07	7.96	7.13
150	1.53	7.37	0.25	11.89	9.79	1.62	7.63	0.22	12.19	9.61
200	1.25	10.85	0.41	17.27	17.54	1.28	11.54	0.38	19.62	15.25
270	1.29	8.19	2.07	18.08	21.33	1.25	11.42	1.84	20.79	15.57
400	1.69	10.48	3.36	20.84	13.53	1.81	10.45	2.95	20.93	14.02
-400	1.68	5.52	3.62	4.50	5.25	1.76	4.53	3.19	6.06	5.64
AVERAGE	1.51	5.52	1.81	8.09	8.45	1.59	5.95	1.59	8.13	8.13

ALPHA: 11.22

CHEMICAL ASSAYS ADJUSTMENT - RESULTS

ELEMENT: ZINC

MESH NO	UNADJUSTED DATA RMD	CF	COF	CUF	BMD	ADJUSTED DATA RMD	CF	COF	CUF	BMD
28	4.69	5.22	3.68	6.58	6.30	4.68	5.61	-0.18	5.70	8.81
35	5.88	6.04	3.08	7.94	7.62	5.82	7.00	1.19	7.12	7.90
48	6.37	6.08	0.83	5.99	7.23	6.11	6.20	1.40	6.66	6.24
65	4.02	5.94	0.89	11.75	11.15	3.77	8.51	0.61	10.54	10.25
100	3.80	8.29	1.62	11.94	11.23	3.63	8.92	1.65	11.86	10.77
150	3.70	8.99	2.35	11.36	10.09	3.61	8.41	2.48	12.07	10.00
200	3.49	7.42	4.29	6.91	7.02	3.45	6.33	4.43	7.70	7.35
270	3.93	7.54	5.92	6.04	5.91	4.08	6.15	6.01	6.27	7.00
400	4.10	6.03	6.16	6.06	7.44	3.99	6.25	6.25	6.25	7.18
-400	4.80	6.28	6.01	6.40	6.15	4.80	6.07	6.07	6.07	6.58
AVERAGE	4.48	6.95	4.36	8.43	8.18	4.41	7.00	4.41	8.29	8.29

ALPHA: 4.76

CHEMICAL ASSAYS ADJUSTMENT - RESULTS

ELEMENT: IRON

MESH NO	UNADJUSTED DATA RMD	CF	COF	CUF	BMD	ADJUSTED DATA RMD	CF	COF	CUF	BMD
28	5.14	6.36	7.22	6.37	4.80	4.71	5.97	5.73	5.98	10.30
35	4.06	5.08	7.22	5.05	7.98	3.71	5.77	6.62	5.75	7.32
48	4.14	5.06	0.65	5.46	4.59	3.83	5.16	0.57	5.60	5.73
65	2.21	7.05	0.53	10.64	11.86	2.04	8.70	0.46	10.82	11.14
100	1.95	8.81	0.76	16.66	14.81	1.84	11.32	0.61	15.66	14.65
150	2.03	11.64	1.65	18.89	16.66	1.93	12.96	1.43	20.06	16.60
200	1.86	8.17	2.82	20.08	19.13	1.66	12.26	2.40	19.41	16.09
270	1.96	6.09	4.47	17.45	17.45	1.73	10.27	3.81	16.57	13.75
400	2.38	5.16	4.91	17.32	21.41	2.00	10.44	4.22	19.13	13.93
-400	3.19	5.23	5.26	10.32	13.49	2.84	7.91	4.52	11.79	9.96
AVERAGE	3.25	7.07	3.42	12.58	14.13	2.95	9.38	2.95	12.59	12.59

ALPHA: 9.54

APPENDIX V

SIMULATION RESULTS

CONTENT

SECTION V.1

Computer Program to Simulate the Actual Closed Grinding Circuit - $Y_{m,i}$ Matrix Cyclone Model.

V.1.1 Results at 154.2 mtph.

V.1.2 Results at 190.3 mtph.

SECTION V.2

Computer Program to Simulate the Actual Closed Grinding Circuit - Combined Cyclone Model.

V.2.1 Results at 154.2 mtph.

V.2.2 Results at 190.3 mtph.

SECTION V.3

Computer Program to Simulate the Proposed Closed Grinding Circuit - $Y_{m,i}$ Matrix Cyclone Model.

V.3.1 Results at 154.2 mtph.

V.3.2 Results at 190.3 mtph.

SECTION V.4

Computer Programs to Simulate the Overall Performance of the Actual Grinding Circuit at 154.2 mtph.

V.4.1 Plug Flow Ball Mill Model - Results.

V.4.2 Tanks-in-Series Ball Mill Model - Results.

```
C
C
C
C     COMPUTER PROGRAM TO SIMULATE A CLOSED GRINDING CIRCUIT
C
C
C     THE PROGRAM ITERATIVELY COMPUTES THE MINERAL FLOW RATES
C
C
C     NOMENCLATURE
C     ------------
C     RHO(I)          SPECIFIC GRAVITY OF PURE MINERALS
C                     (MET TON/CUBIC METRE)
C                     RHO(1)= 7.50     (GALENA)
C                     RHO(2)= 5.00     (PYRITE)
C                     RHO(3)= 4.00     (SPHALERITE)
C                     RHO(4)= 2.85     (CALCITE-DOLOMITE)
C
C     RHOU(I)         SPECIFIC GRAVITY OF PURE MINERALS
C                     (UNITS/CUBIC METRE)
C     FACTOR(I)       STOICHIOMETRIC FACTOR FOR CONVERTING
C                     ELEMENT ASSAYS TO MINERAL ASSAYS
C                     FACTOR(1)= 1.15     (GALENA - PBS)
C                     FACTOR(2)= 1.48     (SPHALERITE - ZNS)
C                     FACTOR(3)= 2.15     (PYRITE - FES2)
C
C     TON             CONVERTION FACTOR  (METRIC TONNES TO
C                     MINERAL UNITS)
C     UNIT            CONVERTION FACTOR  (MINERAL UNITS TO
C                     METRIC TONNES)
C     BMH             VOLUMETRIC BALL MILL HOLDUP (CUBIC METRES)
C     TIME            BALL MILL RESIDENCE TIME (MINUTES)
C     P(I,J)          ORDER OF BREAKAGE (SIZE-BY-SIZE AND
C                     MINERAL-BY-MINERAL)
C     B(I,J)          CUMULATIVE-BASIS SPECIFIC RATE-OF-BREAKAGE
C     Y(I,J)          CYCLONE SELECTIVITY INDEX
C     FICHEM(I,J)     SIZE-BY-SIZE ELEMENT ASSAYS OF ROD MILL
C                     DISCHARGE  (PERCENT)
C     FG(I)           GRIND SCALING FACTOR  (A FITTING PARAMETER)
C     K(I,J)          INSTANTANEOUS RATE-OF-BREAKAGE
C                     (SIZE-BY-SIZE AND MINERAL-BY-MINERAL)
C     CLOV            OVERALL CIRCULATING LOAD  (PERCENT)
C     CLMIN(I)        MINERAL CIRCULATING LOAD  (PERCENT)
C     WADD            MAKE-UP WATER ADDITION TO SUMP
C                     (CUBIC METRES/MIN)
C     V(I)            VOLUMETRIC MINERAL FLOW RATES IN BALL
C                     MILL FEED  (CUBIC METRE/MIN)
C     VT              TOTAL VOLUMETRIC OF SOLIDS IN BALL MILL
C                     FEED  (CUBIC METRE/MIN)
C
C
C     NOTE:   THE GRIND CIRCUIT CONTAINS FIVE STREAMS
C             STREAM 1:   ROD MILL DISCHARGE ('FRESH FEED')
C             STREAM 2:   CYCLONE FEED
C             STREAM 3:   CYCLONE OVERFLOW (TO FLOTATION)
C             STREAM 4:   CYCLONE UNDERFLOW (BALL MILL FEED)
C             STREAM 5:   BALL MILL DISCHARGE
C
```

CONTINUED ......

```
C       THE FOLLOWING TERMS REFER TO THE ABOVE DEFINED STREAMS:
C
C       M1T TO M5T          TOTAL SOLIDS MASS FLOW RATE
C                           (UNITS/MIN)
C       PCTS1 TO PCTS5      PERCENT SOLIDS OF PULP
C       F1(I) TO F5(I)      SIZE ASSAYS OF SOLIDS
C       FF1(I) TO FF5(I)        CUMULATIVE WEIGHT PERCENT FINER
C       R1(I) TO R5(I)          CUMULATIVE MINERAL UNITS COARSER
C                               (UNITS/MIN)
C       Z1(I,J) TO Z5(I,J)  PERCENT MINERAL FREQUENCY DISTRIBUTION
C       ZF1(I,J) TO ZF5(I,J)  CUMULATIVE MINERAL DISTRIBUTION
C                             COARSER  (UNITS/MIN)
C       FM1(I,J) TO FM5(I,J)  CUMULATIVE MINERAL DISTRIBUTION
C                             FINER  (UNITS/MIN)
C
C
C
      CHARACTER*7 ELEM(4)
      DIMENSION F1(10),F2(10),F3(10),F4(10),F5(10),F1U(10)
      DIMENSION FF1(10),FF2(10),FF3(10),FF4(10),FF5(10)
      DIMENSION F1MU(10,4),F2MU(10,4),F3MU(10,4),F4MU(10,4),F5MU(10,4)
      DIMENSION F1MUC(10,4),F2MUC(10,4),F3MUC(10,4),F4MUC(10,4)
      DIMENSION F5MUC(10,4),CLMIN(4)
      DIMENSION F1CHEM(10,3),Y(10,4),B(9,4),P(9,4)
      DIMENSION V(4),RHO(4),RHOU(4),MESH(10),LAPERT(10),FACTOR(3)
      DIMENSION R1(10),R2(10),R3(10),R4(10),R5(10)
      DIMENSION Z1(10,4),Z2(10,4),Z3(10,4),Z4(10,4),Z5(10,4)
      DIMENSION ZF1(10,4),ZF2(10,4),ZF3(10,4),ZF4(10,4),ZF5(10,4)
      DIMENSION FM1(10,4),FM2(10,4),FM3(10,4),FM4(10,4),FM5(10,4)
      DIMENSION FG(4),YC(10,4)
      REAL M1T,M2T,M3T,M4T,M5T,K(9,4)
      READ(5,1)BMH,SOL1
      READ(5,2)(RHO(I),I=1,4)
      READ(5,3)(MESH(I),I=1,10)
      READ(5,4)(LAPERT(I),I=1,10)
      READ(5,5)(FACTOR(I),I=1,3)
      READ(5,6)(F1(I),I=1,10)
      READ(5,7)((F1CHEM(I,J),I=1,10),J=1,3)
      READ(5,9)((P(I,J),I=1,9),J=1,4)
      READ(5,9)((B(I,J),I=1,9),J=1,4)
      READ(5,8)(ELEM(I),I=1,4)
      READ(5,11)((Y(I,J),I=1,10),J=1,4)
    1 FORMAT(F8.6,1X,F5.1)
    2 FORMAT(4F4.2)
    3 FORMAT(10I4)
    4 FORMAT(I3,9(1X,I3))
    5 FORMAT(3(1X,F4.2))
    6 FORMAT(10F5.2)
    7 FORMAT(10F5.2)
    8 FORMAT(4A7)
    9 FORMAT(9(1X,F6.4))
   11 FORMAT(10F7.4)
C
C       DEFINITION OF PARAMETERS TO BE CONSTANT
C       TRHOUGH THE ITERATIVE PROCESS
C
      FG(1)= 0.70
      FG(2)= 1.00
```

CONTINUED ......

```
      FG(3)= 1.
      FG(4)= 1.00
C
      PCTS1= 77.
      RF= 34.
      VW1= (100.*SOL1/PCTS1 - SOL1)/60.
      VW5= 210./60.
      TON= 6.E5/SOL1
      UNIT= 1./TON
      NIT= 1.E4
      DO 10 I=1,4
      RHOU(I)= TON*RHO(I)
   10 CONTINUE
      DO 20 J=1,3
      A= 0.0
      DO 20 I=1,10
      F1MU(I,J)= F1(I)*F1CHEM(I,J)*FACTOR(J)
      F1MUC(I,J)= A + F1MU(I,J)
      A= F1MUC(I,J)
   20 CONTINUE
      A= 0.0
      DO 30 I=1,10
      F1MU(I,4)= 100.*F1(I) - (F1MU(I,1)+F1MU(I,2)+F1MU(I,3))
      F1MUC(I,4)= A + F1MU(I,4)
      A= F1MUC(I,4)
   30 CONTINUE
      DO 40 J=1,4
      DO 40 I=1,10
      F5MU(I,J)= 0.0
   40 CONTINUE
      VW5= 0.0
C
C     BEGINNING OF THE ITERATIVE PROCESS
C
      N= 1
   15 DO 50 J=1,4
C
C
C
C     SUMP
C
C
      A= 0.0
      DO 50 I=1,10
      F2MU(I,J)= F1MU(I,J) + F5MU(I,J)
      F2MUC(I,J)= A + F2MU(I,J)
      A= F2MUC(I,J)
   50 CONTINUE
      VW2= VW1 + VW5
      DO 52 I=1,10
      A= 0.0
      B1= 0.0
      DO 52 J=1,4
      F1U(I)= A + F1MUC(I,J)
      F2(I)= B1 + F2MUC(I,J)
      A= F1U(I)
      B1= F2(I)
   52 CONTINUE
```

CONTINUED ....

```
      A= 0.0
      DO 55 I=1,4
      M2T= A + F2MUC(10,I)
      A= M2T
   55 CONTINUE
      PCTS2= 100.*UNIT*M2T/(UNIT*M2T + VW2)
      DO 57 I=1,10
      FF1(I)= 100.*(M1T - F1U(I))/M1T
      FF2(I)= 100.*(M2T - F2(I))/M2T
   57 CONTINUE
C
C
C     CYCLONE
C
C
      VW4= RF*VW2/100.
      DO 60 J=1,4
      A= 0.0
      B1= 0.0
      DO 60 I=1,10
      F4MU(I,J)= Y(I,J)*F2MU(I,J)/100.
      F3MU(I,J)= F2MU(I,J) - F4MU(I,J)
      F4MUC(I,J)= A + F4MU(I,J)
      F3MUC(I,J)= B1 + F3MU(I,J)
      A= F4MUC(I,J)
      B1= F3MUC(I,J)
   60 CONTINUE
      B1= 0.0
      C= 0.0
      DO 70 J=1,4
      V(J)= F4MUC(10,J)/RHOU(J)
      M3T= B1 + F3MUC(10,J)
      M4T= C + F4MUC(10,J)
      B1= M3T
      C= M4T
   70 CONTINUE
      SOL4= M4T*UNIT
      WADD= VW5 - VW4
C
C
C     BALL MILL
C
C
      VT= V(1) + V(2) + V(3) + V(4)
      RHOT= UNIT*M4T/VT
      TIME= BMH/(VW4 + VT)
      DO 80 J=1,4
      DO 80 I=1,9
      F5MUC(I,J)= F4MUC(I,J)*EXP(-FG(J)*B(I,J)*TIME**P(I,J))
   80 CONTINUE
      DO 90 J=1,4
      F5MUC(10,J)= F4MUC(10,J)
      F5MU(1,J)= F5MUC(1,J)
   90 CONTINUE
      A= 0.0
      DO 95 J=1,4
      M5T= A + F5MUC(10,J)
      A= M5T
```

CONTINUED ......

```
  95  CONTINUE
      DO 100 J=1,4
      DO 100 I=2,10
      L= I - 1
      F5MU(I,J)= F5MUC(I,J) - F5MUC(L,J)
 100  CONTINUE
      VW3= VW2 - VW4
C
      DO 110 I=1,10
      C= 0.0
      D1= 0.0
      E= 0.0
      R1(I)= 0.0
      R2(I)= 0.0
      R3(I)= 0.0
      R4(I)= 0.0
      R5(I)= 0.0
C
      DO 110 J=1,4
      F3(I)= C + F3MUC(I,J)
      F4(I)= D1 + F4MUC(I,J)
      F5(I)= E + F5MUC(I,J)
      R1(I)= R1(I) + F1MU(I,J)
      R2(I)= R2(I) + F2MU(I,J)
      R3(I)= R3(I) + F3MU(I,J)
      R4(I)= R4(I) + F4MU(I,J)
      R5(I)= R5(I) + F5MU(I,J)
      C= F3(I)
      D1= F4(I)
      E= F5(I)
 110  CONTINUE
      DO 120 I=1,10
      FF1(I)= 100.*(M1T - F1U(I))/M1T
      FF2(I)= 100.*(M2T - F2(I))/M2T
      FF3(I)= 100.*(M3T - F3(I))/M3T
      FF4(I)= 100.*(M4T - F4(I))/M4T
      FF5(I)= 100.*(M5T - F5(I))/M5T
 120  CONTINUE
      DO 130 J=1,4
      CLMIN(J)= 100.*F4MUC(10,J)/F1MUC(10,J)
 130  CONTINUE
      CLOV= 100.*M4T/M1T
      PCTS3= 100.*UNIT*M3T/(UNIT*M3T + VW3)
      PCTS4= 100.*UNIT*M4T/(UNIT*M4T + VW4)
      PCTS5= PCTS4
      A= ABS(M1T - M3T)
C
C
C
C    CONVERGENCE TEST OF STEADY STATE MASS FLOW CONDITIONS
C
C
C
      IF((A.LE.10.).OR.(M.EQ.50))GO TO 140
      M= M+1
      GO TO 15
C
C
C     END OF ITERATIVE PROCESS
```

CONTINUED ......

```
140   DO 145 J=1,4
      S1= 0.0
      S2= 0.0
      S3= 0.0
      S4= 0.0
      S5= 0.0
      DO 145 I=1,10
      Z1(I,J)= 100.*F1MU(I,J)/F1MUC(10,J)
      Z2(I,J)= 100.*F2MU(I,J)/F2MUC(10,J)
      Z3(I,J)= 100.*F3MU(I,J)/F3MUC(10,J)
      Z4(I,J)= 100.*F4MU(I,J)/F4MUC(10,J)
      Z5(I,J)= 100.*F5MU(I,J)/F5MUC(10,J)
      ZF1(I,J)= S1 + Z1(I,J)
      ZF2(I,J)= S2 + Z2(I,J)
      ZF3(I,J)= S3 + Z3(I,J)
      ZF4(I,J)= S4 + Z4(I,J)
      ZF5(I,J)= S5 + Z5(I,J)
      FM1(I,J)= 100. - ZF1(I,J)
      FM2(I,J)= 100. - ZF2(I,J)
      FM3(I,J)= 100. - ZF3(I,J)
      FM4(I,J)= 100. - ZF4(I,J)
      FM5(I,J)= 100. - ZF5(I,J)
      S1= ZF1(I,J)
      S2= ZF2(I,J)
      S3= ZF3(I,J)
      S4= ZF4(I,J)
      S5= ZF5(I,J)
145   CONTINUE
      DO 199 J=1,4
      DO 199 I=1,10
      YC(I,J)= 100.*YC(I,J)
199   CONTINUE
      WRITE(6,310)SOL1,BMH,(FG(I),I=1,4)
      DO 301 I=1,9
      WRITE(6,315)MESH(I),F1(I),(F1CHEM(I,J),J=1,3),(B(I,J),J=1,4),(P(I,
     @J),J=1,4)
301   CONTINUE
310   FORMAT('1'//' ',15X,'INPUT DATA USED IN SIMULATING A PB-ZN ORE GRI
     @NDING OPERATION'//' ',15X,'FLOW RATE INPUT (FRESH FEED):',F10.2,'
     @METRIC TONS PER HOUR'/' ',15X,'BALL MILL HOLDUP:',16X,F6.2,' CUBIC
     @ METERS'//' ',15X,'GRINDING SCALE FACTOR FOR PBS:',F10.2//' ',15X,
     @'GRINDING SCALE FACTOR FOR ZNS:',F10.2//' ',15X,
     @'GRINDING SCALE FACTOR FOR FES2:',F9.2//' ',15X,
     @'GRINDING SCALE FACTOR FOR CAL/DOL:',F6.2/////' ',15X,
     @'MESH',3X,'SIZE',3X,'CHEMICAL  ASSAYS',5X,'SPECIFIC RATE OF BREAKA
     @GE',7X,'P  ORDER OF BREAKAGE'/' ',16X,'NO',3X,'ASSAYS',4X,'PB',4X,
     @'ZN',4X,'FE',10X,'PBS',3X,'ZNS',2X,'FES2 CAL/DOL',4X,'PBS',4X,
     @'ZNS',2X,'FES2 CAL/DOL'//)
315   FORMAT(' ',15X,I4,2X,F6.2,1X,3F6.2,3X,4F7.4,2X,4F7.4)
      WRITE(6,316)MESH(10),F1(10),(F1CHEM(10,J),J=1,3)
316   FORMAT(' ',15X,I4,2X,F6.2,1X,3F6.2)
      WRITE(6,700)(D50C(I),I=1,4)
700   FORMAT(///15X,'THE CORRECTED D50C VALUES ARE:'//20X,'PBS:',F12.2/
     @20X,'ZNS:',F12.2/20X,'FES2:',F11.2/20X,'CAL/DOL:',F8.2)
      WRITE(6,200)M,RHOT,TIME,CLOV,(CLMIN(J),J=1,4),PCTS1,PCTS2,PCTS3,
     @PCTS4,PCTS5
200   FORMAT('1'///' ',22X,'ITERATION:',I3,18X,'SP. GR. BALL MILL FEED:'
```

CONTINUED ......

```
     @.F5.2/' ',22X,'RESIDENCE TIME:',F5.2,' MIN',11X,'TOTAL CIRC. LOAD:
     @',F7.2//' ',31X,'PBS C.L.  ',F6.2,11X,'ZNS C.L. ',F6.2/' ',
     @31X,'FES2 C.L. ',F6.2,7X,'CAL/DOL C.L. ',F6.2//' ',31X,
     @'PCT SOLIDS BY WT, STREAM NO ONE:',F9.2/' ',31X,
     @'PCT SOLIDS BY WT, STREAM NO TWO:',F9.2/' ',31X,'PCT SOLIDS BY WT,
     @ STREAM NO THREE:',F7.2/' ',31X,'PCT SOLIDS BY WT, STREAM NO FOUR:
     @',F8.2/' ',31X,'PCT SOLIDS BY WT, STREAM NO FIVE:',F8.2///' ',
     @'CUMULATIVE WT PCT FINER - OVERALL'///)
      WRITE(6,210)
210   FORMAT(' ',14X,'MESH',4X,'SIZE'/' ',15X,'NO',5X,'MICR',3X,
     @'STREAM 1',1X,'STREAM 2',1X,'STREAM 3',1X,'STREAM 4',1X,'STREAM 5'
     @)
      DO 220 I=1,9
      WRITE(6,250)MESH(I),LAPERT(I),FF1(I),FF2(I),FF3(I),FF4(I),FF5(I)
250   FORMAT(' ',14X,I4,5X,I3,5(3X,F6.2)//)
220   CONTINUE
      J1= 1
      J2= 2
      J3= 3
      J4= 4
      J5= 5
      WRITE(6,255)J1
      DO 146 I=1,10
      WRITE(6,260)MESH(I),LAPERT(I),R1(I),(F1MU(I,J),J=1,4)
146   CONTINUE
      WRITE(6,255)J2
      DO 150 I=1,10
      WRITE(6,260)MESH(I),LAPERT(I),R2(I),(F2MU(I,J),J=1,4)
150    CONTINUE
      WRITE(6,255)J3
      DO 160 I=1,10
      WRITE(6,260)MESH(I),LAPERT(I),R3(I),(F3MU(I,J),J=1,4)
160   CONTINUE
      WRITE(6,255)J4
      DO 170 I=1,10
      WRITE(6,260)MESH(I),LAPERT(I),R4(I),(F4MU(I,J),J=1,4)
170   CONTINUE
      WRITE(6,255)J5
      DO 180 I=1,10
      WRITE(6,260)MESH(I),LAPERT(I),R5(I),(F5MU(I,J),J=1,4)
180   CONTINUE
255   FORMAT('1'////,22X,'MINERAL UNITS RETAINED',10X,'STREAM NO: ',
     @I2//' ',22X,'MESH',4X,'SIZE'/' ',23X,'NO',5X,'MICR',5X,'OVERALL',
     @5X,'PBS',6X,'ZNS',5X,'FES2',3X,'CAL/DOL'/)
260   FORMAT(' ',22X,I4,5X,I3,3X,5F9.2//)
      WRITE(6,265)J1
      DO 181 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z1(I,J),J=1,4)
181   CONTINUE
      WRITE(6,265)J2
      DO 182 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z2(I,J),J=1,4)
182   CONTINUE
      WRITE(6,265)J3
      DO 183 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z3(I,J),J=1,4)
183   CONTINUE
      WRITE(6,265)J4
```

CONTINUED ......

```
      DO 184 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z4(I,J),J=1,4)
  184 CONTINUE
      WRITE(6,265)J5
      DO 185 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z5(I,J),J=1,4)
  185 CONTINUE
  265 FORMAT('1'////' ',22X,'MINERAL DISTRIBUTION, PCT',7X,'STREAM NO: '
     @,I2//' ',22X,'MESH',4X,'SIZE'/' ',23X,'NO',5X,'MICR',5X,'PBS',
     @6X,'ZNS',4X,'FES2',4X,'CAL/DOL'/)
  270 FORMAT(' ',22X,I4,5X,I3,5(3X,F6.2)//)
      WRITE(6,275)J1
      DO 191 I=1,9
      WRITE(6,280)MESH(I),LAPERT(I),(FM1(I,J),J=1,4)
  191 CONTINUE
      WRITE(6,275)J2
      DO 192 I=1,9
      WRITE(6,280)MESH(I),LAPERT(I),(FM2(I,J),J=1,4)
  192 CONTINUE
      WRITE(6,275)J3
      DO 193 I=1,9
      WRITE(6,280)MESH(I),LAPERT(I),(FM3(I,J),J=1,4)
  193 CONTINUE
      WRITE(6,275)J4
      DO 194 I=1,9
      WRITE(6,280)MESH(I),LAPERT(I),(FM4(I,J),J=1,4)
  194 CONTINUE
      WRITE(6,275)J5
      DO 195 I=1,9
      WRITE(6,280)MESH(I),LAPERT(I),(FM5(I,J),J=1,4)
  195 CONTINUE
  275 FORMAT('1'////' ',22X,'CUM MINERAL PCT FINER',3X,'STREAM NO: ',
     @I2//' ',22X,'MESH',4X,'SIZE',/' ',23X,'NO',5X,'MICR',5X,'PBS',
     @6X,'ZNS',4X,'FES2',4X,'CAL/DOL'/)
  280 FORMAT(' ',22X,I4,5X,I3,5(3X,F6.2)//)
C
C
C     CALCULATING THE INSTANTANEOUS RATE-OF-BREAKAGE
C
C
      DO 147 J=1,4
      DO 147 I=1,9
      K(I,J)= B(I,J)*TIME**(P(I,J) - 1.)*FG(J)
  147 CONTINUE
      WRITE(6,303)
      DO 196 I=1,9
      WRITE(6,304)MESH(I),LAPERT(I),(K(I,J),J=1,4)
  196 CONTINUE
  303 FORMAT('1'////' ',15X,'INSTANTANEOUS RATES OF BREAKAGE AT THE TIME
     @'/' ',57X,'-1'/' ',15X,'STEADY STATE CONDITIONS WERE REACHED, MIN'
     @//' ',15X,'MESH',4X,'SIZE'/' ',16X,'NO',5X,'MICR',5X,'PBS',6X,'ZNS
     @',5X,'FES2',4X,'CAL/DOL'/)
  304 FORMAT(' ',15X,I4,5X,I3,4(4X,F5.3)//)
      STOP
      END
$DATA
C
C ... DATA CARDS
```

V.1.1 Results at 154.2 mtph

INPUT DATA USED IN SIMULATING A PB-ZN ORE GRINDING OPERATION

FLOW RATE INPUT (FRESH FEED): 154.20 METRIC TONS PER HOUR
BALL MILL HOLDUP: 8.37 CUBIC METERS

GRINDING SCALE FACTOR FOR PBS: 0.70

GRINDING SCALE FACTOR FOR ZNS: 1.00

GRINDING SCALE FACTOR FOR FES2: 1.00

GRINDING SCALE FACTOR FOR CAL/DOL: 1.00

MESH NO	SIZE ASSAYS	CHEMICAL ASSAYS PB	ZN	FE	SPECIFIC RATE OF BREAKAGE PBS	ZNS	FES2	CAL/DOL	P ORDER OF BREAKAGE PBS	ZNS	FES2	CAL/DOL
28	19.42	1.48	4.99	10.23	0.9141	0.7581	0.6797	0.6840	0.7483	0.8145	0.6452	0.8773
35	7.96	1.25	6.01	6.95	0.8155	0.6548	0.4826	0.5842	0.7852	0.9210	0.8653	0.9973
48	7.39	2.17	7.49	8.35	0.5981	0.4711	0.3380	0.3730	0.9831	1.0460	0.9808	1.1673
65	5.72	1.40	5.19	5.97	0.3948	0.3164	0.2430	0.2779	1.1088	1.0766	0.9803	1.1622
100	7.62	2.94	8.45	6.76	0.2708	0.1808	0.1329	0.1725	1.0421	1.0457	0.9213	1.1588
150	9.05	1.55	5.22	4.46	0.1615	0.0990	0.0601	0.1631	1.0365	1.0890	1.2340	0.9272
200	8.16	1.37	4.94	4.01	0.1085	0.0737	0.0476	0.0934	0.9679	0.9770	1.0694	1.0294
270	8.66	1.59	5.54	4.40	0.0813	0.0408	0.0314	0.0573	0.7736	1.0535	1.0053	1.0866
400	5.38	1.64	5.62	4.45	0.0595	0.0318	0.0239	0.0444	0.7825	1.0498	1.0511	1.0577
-400	20.66	1.59	6.00	5.88								

ITERATION: 23
RESIDENCE TIME: 3.26 MIN

SP. GR. BALL MILL FEED: 3.63
TOTAL CIRC. LOAD: 157.11

PBS C.L. 536.54
FES2 C.L. 379.72

ZNS C.L. 221.82
CAL/DCL C.L. 98.14

PCT SOLIDS BY WT. STREAM NO ONE: 77.00
PCT SOLIDS BY WT. STREAM NO TWO: 60.75
PCT SOLIDS BY WT. STREAM NO THREE: 47.69
PCT SOLIDS BY WT. STREAM NO FOUR: 73.56
PCT SOLIDS BY WT. STREAM NO FIVE: 73.56

CUMULATIVE WT PCT FINER - OVERALL

MESH NO	SIZE MICR	STREAM 1	STREAM 2	STREAM 3	STREAM 4	STREAM 5
28	592	80.58	90.97	99.50	85.55	97.59
35	419	72.62	87.16	99.09	79.57	96.42
48	296	65.23	82.20	98.08	72.10	93.01
65	209	59.51	76.28	95.50	64.06	86.96
100	148	51.89	64.04	87.01	49.43	71.78
150	105	42.64	50.92	75.49	35.29	56.06
200	74	34.68	37.61	61.42	22.47	39.48
270	53	26.02	26.17	45.64	13.79	26.26
400	37	20.64	20.53	36.59	10.32	20.45

MINERAL DISTRIBUTICN. PCT STREAM NC: 1

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	17.34	16.60	30.19	17.77
35	419	6.00	8.19	8.41	7.90
48	296	9.67	9.48	9.38	6.71
65	209	4.83	5.08	5.19	5.91
100	148	13.51	11.03	7.63	7.04
150	105	8.46	8.09	6.13	9.72
200	74	6.74	6.90	4.57	8.94
270	53	8.31	8.22	5.79	9.26
400	37	5.32	5.18	3.64	5.73
-400	-37	19.81	21.23	18.46	21.02

MINERAL DISTRIBUTICN. PCT STREAM NO: 2

MESH NO	SIZE MICP	PBS	ZNS	FES2	CAL/DOL
28	592	3.46	5.97	8.19	10.44
35	419	1.32	3.00	2.60	4.71
48	296	2.23	4.27	4.19	5.66
65	209	2.22	4.74	5.10	6.81
100	148	7.41	15.01	15.00	10.86
150	105	11.74	17.99	16.59	10.56
200	74	17.78	13.83	16.35	11.46
270	53	25.57	11.33	12.73	9.73
400	37	10.41	5.28	3.80	6.16
-400	-37	17.86	18.59	15.05	23.61

MINERAL DISTRIBUTICN. PCT STREAM NO: 3

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	0.25	0.21	0.40	0.56
35	419	0.46	0.13	1.12	0.30
48	296	0.00	0.00	0.24	1.30
65	209	0.00	0.18	0.99	3.22
100	148	0.96	1.63	6.30	9.87
150	105	1.59	10.69	4.07	13.27
200	74	1.98	14.73	11.76	14.72
270	53	10.42	19.86	19.01	14.83
400	37	14.51	9.99	9.33	8.75
-400	-37	69.84	42.57	46.77	33.17

MINERAL DISTRIBUTION. PCT STREAM NO: 4

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	4.04	8.56	10.23	20.50
35	419	1.48	4.30	2.99	9.21
48	296	2.64	6.19	5.23	10.10
65	209	2.63	6.80	6.18	10.47
100	148	8.59	21.03	17.28	11.86
150	105	13.60	21.27	20.38	7.80
200	74	20.67	13.42	17.55	8.14
270	53	28.35	7.49	11.08	4.53
400	37	9.66	3.15	2.35	3.51
-400	-37	8.35	7.78	6.74	13.86

MINERAL DISTRIBUTION. PCT STREAM NO: 5

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	0.86	1.17	2.18	2.98
35	419	0.44	0.66	1.07	1.47
48	296	0.84	1.92	2.63	4.59
65	209	1.73	4.59	5.07	7.73
100	148	6.24	16.80	16.88	14.75
150	105	12.32	22.45	19.87	11.42
200	74	19.82	16.95	19.36	14.03
270	53	28.87	12.73	14.86	10.20
400	37	11.38	5.32	3.64	6.59
-400	-37	17.49	17.39	14.15	26.24

CUM MINERAL PCT FINER STREAM NO: 1

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	82.66	83.40	69.81	82.23
35	419	76.66	75.21	61.40	74.33
48	296	66.99	65.73	52.02	67.62
65	209	62.16	60.65	46.83	61.71
100	148	48.65	49.62	39.00	54.67
150	105	40.18	41.53	32.87	44.95
200	74	33.44	34.62	27.89	36.01
270	53	25.14	26.41	22.10	26.75
400	37	19.81	21.23	18.46	21.02

CUM MINERAL PCT FINER STREAM NO: 2

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	96.54	94.03	91.81	89.56
35	419	95.22	91.03	89.21	84.85
48	296	92.99	86.76	85.02	79.18
65	209	90.77	82.02	79.92	72.37
100	148	83.36	67.01	64.91	61.52
150	105	71.62	49.02	47.92	50.95
200	74	53.84	35.19	31.58	39.49
270	53	28.27	23.86	18.85	29.77
400	37	17.86	18.59	15.05	23.61

CUM MINERAL PCT FINER STREAM NO: 3

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	99.75	99.79	99.60	99.44
35	419	99.28	99.66	98.48	99.14
48	296	99.28	99.66	98.24	97.83
65	209	99.28	99.48	97.25	94.61
100	148	98.32	97.84	90.94	84.75
150	105	96.74	87.15	86.87	71.48
200	74	94.76	72.41	75.11	56.76
270	53	84.34	52.56	56.09	41.93
400	37	69.84	42.57	46.77	33.17

CUM MINERAL PCT FINER STREAM NO: 4

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	95.96	91.44	89.77	79.50
35	419	94.48	87.14	86.78	70.29
48	296	91.84	80.95	81.55	60.18
65	209	89.21	74.15	75.37	49.71
100	148	80.63	53.11	58.09	37.85
150	105	67.03	31.84	37.71	30.04
200	74	46.36	18.42	20.16	21.91
270	53	18.01	10.93	9.08	17.38
400	37	8.35	7.78	6.74	13.86

CUM MINERAL PCT FINER STREAM NO: 5

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	99.14	98.83	97.62	97.02
35	419	98.70	98.16	96.55	95.56
48	296	97.86	96.24	93.72	90.97
65	209	96.13	91.65	88.65	83.23
100	148	89.89	74.85	71.77	68.48
150	105	77.57	52.40	51.90	57.07
200	74	57.74	35.44	32.55	43.04
270	53	28.87	22.71	17.99	32.83
400	37	17.49	17.39	14.15	26.24

INSTANTANEOUS RATES CF BREAKAGE AT THE TIME STEADY STATE CJNDITICNS WERE REACHED, MIN^{-1}

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	0.475	0.609	0.447	0.592
35	419	0.443	0.596	0.412	0.582
48	296	0.410	0.497	0.330	0.455
65	209	0.314	0.346	0.237	0.337
100	148	0.199	0.191	0.121	0.208
150	105	0.118	0.110	0.079	0.150
200	74	0.073	0.072	0.052	0.097
270	53	0.044	0.043	0.032	0.063
400	37	0.032	0.034	0.025	0.048

V.1.2 Results at 190.3 mtph

INPUT DATA USED IN SIMULATING A PB-ZN ORE GRINDING OPERATION

FLOW RATE INPUT (FRESH FEED): 190.30 METRIC TONS PER HOUR
BALL MILL HOLDUP: 8.37 CUBIC METERS

GRINDING SCALE FACTOR FOR PBS: 1.70

GRINDING SCALE FACTOR FOR ZNS: 1.00

GRINDING SCALE FACTOR FOR FES2: 1.00

GRINDING SCALE FACTOR FOR CAL/DOL: 1.00

MESH NO.	SIZE ASSAYS	CHEMICAL ASSAYS PB	ZN	FE	SPECIFIC RATE OF BREAKAGE PBS	ZNS	FES2	CAL/DOL	P ORDER OF BREAKAGE PBS	ZNS	FES2	CAL/DOL
28	24.24	1.44	4.68	4.71	0.9141	0.7581	0.6797	0.6646	0.7483	0.8146	0.6462	0.8773
35	5.94	2.32	5.82	3.71	0.8155	0.6548	0.4826	0.5842	0.7852	0.9219	0.8653	0.9973
48	6.31	2.75	6.11	3.93	0.5581	0.4711	0.3363	0.3730	0.9631	1.0466	0.5808	1.1673
65	6.10	0.43	3.77	2.?4	0.3948	0.3164	0.2433	0.2779	1.1088	1.0765	0.9603	1.1622
100	10.20	1.58	3.63	1.84	0.2708	0.1808	0.1329	0.1725	1.0421	1.0457	0.9213	1.1598
150	10.33	1.02	3.61	1.03	0.1615	0.0990	0.0601	0.1031	1.0365	1.0690	1.2340	0.9272
200	8.12	1.28	3.49	1.66	0.1088	0.0737	0.0470	0.0934	0.9679	0.9770	1.0694	1.0294
270	7.47	1.25	4.15	1.73	0.0813	0.0418	0.0314	0.0573	0.7736	1.0535	1.0053	1.0865
400	3.84	1.41	3.99	2.10	0.0595	0.0318	0.0239	0.0444	0.7625	1.0498	1.0511	1.0577
-400	17.41	1.78	4.81	2.84								

ITERATION: 36
RESIDENCE TIME: 1.88 MIN

SP. GR. BALL MILL FEED: 3.53
TOTAL CIRC. LOAD: 196.47

PBS C.L. 830.13
FES2 C.L. 814.43

ZNS C.L. 363.89
CAL/DOL C.L. 123.81

PCT SOLIDS BY WT. STREAM NO ONE: 78.80
PCT SOLIDS BY WT. STREAM NO TWO: 62.10
PCT SOLIDS BY WT. STREAM NO THREE: 50.76
PCT SOLIDS BY WT. STREAM NO FOUR: 70.96
PCT SOLIDS BY WT. STREAM NO FIVE: 70.96

CUMULATIVE WT PCT FINER - CVERALL

MESH NO	SIZE MICR	STREAM 1	STREAM 2	STREAM 3	STREAM 4	STREAM 5
28	592	75.76	88.25	99.14	82.78	94.67
35	419	69.82	84.66	98.94	77.49	92.22
48	296	63.51	77.91	97.24	68.07	85.24
65	209	57.41	71.45	91.69	59.66	77.10
100	148	47.21	56.61	77.57	45.96	61.41
150	105	36.48	43.47	64.96	32.54	46.83
200	74	28.70	32.15	49.70	23.22	33.87
270	53	21.29	22.91	36.06	16.26	23.74
400	37	17.41	18.91	29.10	13.74	19.68

MINERAL DISTRIBUTION, PCT STREAM NO: 1

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	21.92	25.09	39.66	23.1[illegible]
35	419	8.65	7.83	7.47	5.62
48	296	15.89	8.73	6.15	5.86
65	209	1.68	5.21	4.22	6.4[illegible]
100	148	17.12	8.39	9.36	10.63
150	105	15.51	8.45	6.75	11.74
200	74	6.53	6.42	4.57	8.55
270	53	5.86	5.85	4.38	7.78
400	37	4.42	3.52	2.64	4.0[illegible]
-400	-37	19.46	18.93	16.75	17.30

MINERAL DISTRIBUTION, PCT STREAM NO: 2

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	3.67	7.70	6.56	14.63
35	419	1.73	2.76	2.26	4.36
48	296	2.81	4.68	3.72	8.28
65	209	2.59	6.63	4.65	8.66
100	148	7.70	10.37	14.55	13.75
150	105	15.51	22.64	21.66	8.77
200	74	20.[illegible]	11.21	13.58	9.88
270	53	17.61	9.22	10.94	7.97
400	37	9.26	3.14	4.37	3.56
-400	-37	19.12	15.64	17.43	19.87

MINERAL DISTRIBUTION, PCT STREAM NO: 3

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	0.00	0.00	0.82	0.95
35	419	0.[illegible]5	0.[illegible]4	0.47	[illegible].19
48	296	0.31	0.43	0.33	4.92
65	209	0.[illegible]3	0.45	0.46	6.44
100	148	0.27	4.06	2.[illegible]9	16.08
150	105	1.59	11.79	8.45	13.21
200	74	2.63	15.30	12.29	15.88
270	53	13.19	20.76	18.52	12.61
400	37	14.32	8.49	9.49	6.44
-400	-37	67.61	38.73	49.04	26.06

MINERAL DISTRIBUTION, PCT STREAM NO: 4

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	4.11	9.82	7.26	25.67
35	419	1.93	3.50	2.47	7.72
48	296	3.10	5.85	4.13	13.55
65	209	2.99	8.33	5.20	10.81
100	148	6.56	19.75	10.11	11.88
150	105	17.16	25.62	23.46	5.18
200	74	22.06	10.19	13.98	5.04
270	53	18.14	6.[illegible]7	14.02	4.06
400	37	8.66	1.67	3.75	1.23
-400	-37	13.35	9.30	13.59	14.87

MINERAL DISTRIBUTION, PCT STREAM NO: 5

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	1.47	2.76	2.61	7.79
35	419	0.89	1.36	1.61	3.34
48	296	1.83	3.57	3.17	10.36
65	209	2.70	7.02	4.74	11.84
100	148	7.49	18.36	15.89	16.28
150	105	16.[illegible]9	26.54	23.72	7.17
200	74	21.63	12.53	14.72	10.96
270	53	19.08	9.87	11.75	8.12
400	37	9.85	3.[illegible]4	4.58	3.20
-400	-37	19.[illegible]8	14.74	17.52	21.94

CUM MINERAL PCT FINER STREAM NO: 1

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	78.08	74.31	61.32	76.59
35	419	69.43	66.46	53.65	71.25
48	296	58.54	57.75	45.66	65.39
65	209	56.89	52.54	41.45	58.99
100	148	46.77	44.16	35.09	48.36
150	105	36.27	35.71	26.33	37.63
200	74	29.74	29.29	23.77	29.08
270	53	23.88	22.44	19.39	21.33
400	37	19.46	18.93	16.75	17.30

CUM MINERAL PCT FINER STREAM NO: 2

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	96.33	92.30	93.44	85.37
35	419	94.67	89.54	91.16	81.02
48	296	91.79	84.86	87.46	72.65
65	209	89.20	78.23	82.76	63.80
100	148	81.50	61.86	68.16	53.04
150	105	66.00	39.22	46.33	41.28
200	74	46.00	28.01	32.75	31.39
270	53	28.38	18.78	21.80	23.43
400	37	19.12	15.64	17.43	19.87

CUM MINERAL PCT FINER STREAM NO: 3

MESH NO	SIZE MICR	FES	ZNS	FES2	CAL/DOL
28	592	100.00	100.00	99.19	99.05
35	419	99.95	99.96	98.71	98.86
48	296	99.64	99.53	98.36	96.93
65	209	99.61	99.08	97.92	93.49
100	148	99.34	95.02	95.83	74.41
150	105	97.75	83.23	87.34	61.27
200	74	95.12	67.93	77.56	45.32
270	53	81.93	47.23	58.53	32.50
400	37	67.61	38.73	49.04	26.06

CUM MINERAL PCT FINER STREAM NO: 4

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	95.89	90.18	92.74	74.33
35	419	93.96	86.68	90.27	66.62
48	296	90.86	80.83	86.13	53.07
65	209	87.96	72.51	80.93	42.26
100	148	79.38	52.76	64.82	30.37
150	105	62.22	27.14	41.34	25.20
200	74	40.15	17.04	27.36	20.16
270	53	22.01	10.97	17.34	16.10
400	37	13.35	9.30	13.59	14.67

CUM MINERAL PCT FINER STREAM NO: 5

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	98.53	97.24	97.39	92.21
35	419	97.64	95.88	95.78	88.87
48	296	95.81	92.31	92.61	78.51
65	209	93.11	85.29	87.67	67.57
100	148	85.71	66.73	72.28	51.39
150	105	69.62	40.16	46.36	44.22
200	74	47.98	27.65	33.66	33.26
270	53	28.93	17.78	22.10	25.14
400	37	19.08	14.74	17.52	21.94

INSTANTANEOUS RATES OF BREAKAGE AT THE TIME STEADY STATE CONDITIONS WERE REACHED, MIN^{-1}

MESH NO	SIZE MICR	FES	ZNS	FES2	CAL/DOL
28	592	0.546	0.674	0.543	0.632
35	419	0.498	0.623	0.443	0.583
48	296	0.414	0.485	0.234	0.415
65	209	0.296	0.332	0.240	0.308
100	148	0.195	0.166	0.126	0.191
150	105	0.116	0.105	0.070	0.156
200	74	0.074	0.073	0.050	0.095
270	53	0.045	0.042	0.032	0.061
400	37	0.036	0.033	0.025	0.046

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C
C
C
C     COMPUTER PROGRAM TO SIMULATE A CLOSED GRINDING CIRCUIT
C
C
C     THE PROGRAM ITERATIVELY COMPUTES THE MINERAL FLOW RATES
C
C     THE PROGRAM USES THE COMBINED CYCLONE MODEL
C
C
C     NOMENCLATURE
C     ------------
C     RHO(I)              SPECIFIC GRAVITY OF PURE MINERALS
C                         (MET TON/CUBIC METRE)
C                         RHO(1)= 7.50     (GALENA)
C                         RHO(2)= 5.00     (PYRITE)
C                         RHO(3)= 4.00     (SPHALERITE)
C                         RHO(4)= 2.85     (CALCITE-DOLOMITE)
C
C     RHOU(I)             SPECIFIC GRAVITY OF PURE MINERALS
C                         (UNITS/CUBIC METRE)
C     FACTOR(I)           STOICHIOMETRIC FACTOR FOR CONVERTING
C                         ELEMENT ASSAYS TO MINERAL ASSAYS
C                         FACTOR(1)= 1.15     (GALENA - PBS)
C                         FACTOR(2)= 1.48     (SPHALERITE - ZNS)
C                         FACTOR(3)= 2.15     (PYRITE - FES2)
C
C     TON                 CONVERTION FACTOR  (METRIC TONNES TO
C                         MINERAL UNITS)
C     UNIT                CONVERTION FACTOR  (MINERAL UNITS TO
C                         METRIC TONNES)
C     BMH                 VOLUMETRIC BALL MILL HOLDUP (CUBIC METRES)
C     TIME                BALL MILL RESIDENCE TIME (MINUTES)
C     P(I,J)              ORDER OF BREAKAGE (SIZE-BY-SIZE AND
C                         MINERAL-BY-MINERAL)
C     B(I,J)              CUMULATIVE-BASIS SPECIFIC RATE-OF-BREAKAGE
C     Y(I,J)              CYCLONE SELECTIVITY INDEX
C     FICHEM(I,J)         SIZE-BY-SIZE ELEMENT ASSAYS OF ROD MILL
C                         DISCHARGE  (PERCENT)
C     FG(I)               GRIND SCALING FACTOR  (A FITTING PARAMETER)
C     K(I,J)              INSTANTANEOUS RATE-OF-BREAKAGE
C                         (SIZE-BY-SIZE AND MINERAL-BY-MINERAL)
C     CLOV                OVERALL CIRCULATING LOAD  (PERCENT)
C     CLMIN(I)            MINERAL CIRCULATING LOAD  (PERCENT)
C     WADD                MAKE-UP WATER ADDITION TO SUMP
C                         (CUBIC METRES/MIN)
C     V(I)                VOLUMETRIC MINERAL FLOW FATES IN BALL
C                         MILL FEED  (CUBIC METRE/MIN)
C     VT                  TOTAL VOLUMETRIC OF SOLIDS IN BALL MILL
C                         FEED  (CUBIC METRE/MIN)
C
C     GENERAL CYCLONE MODEL (FINCH'S APPROACH)
C     ----------------------------------------
C
C     YP(I,J)             CLASSIFICATION INDEX
C     K1                  SLOPE OF THE REGRESSION LINE OF
C                         LOG(D50C) VS LOG(RHO(I) - 1.)
```

CONTINUED ......

```
C       K2              INTERCEPT OF THE REGRESSION LINE OF ABOVE
C       D50C(J)         CORRECTED CUT-SIZE (MINERAL-BY-MINERAL)
C                       (MICROMETRES)
C       D(I)            PARTICLE SIZE, GEOMETRIC MEAN (MICROMETRES)
C       X               THE RATIO D(I)/D50C(J)
C       N               'SHARPNESS' OF CLASSIFICATION CONSTANT
C
C       THE LYNCH MODEL OF CYCLONE CLASSIFICATION
C       -----------------------------------------
C
C       VF              VORTEX FINDER DIAMETER  (CM)
C       SPIG            SPIGOT DIAMETER (CM)
C       INLET           INLET DIAMETER  (CM)
C       V2(I)           VOLUMETRIC FLOW RATE OF MINERALS IN
C                       CYCLONE FEED  (CUBIC METRES/MIN)
C       Q               VOLUMETRIC FLOW RATE OF PULP IN
C                       CYCLONE FEED  (LITRES/MIN)
C       VT2             TOTAL VOLUMETRIC FLOW RATE OF SOLIDS
C                       IN CYCLONE FEED  (CUBIC METRES/MIN)
C       KL1 TO KL9      CONSTANTS IN THE MATHEMATICAL MODEL
C
C       NOTE:  THE GRIND CIRCUIT CONTAINS FIVE STREAMS.
C              STREAM 1:  ROD MILL DISCHARGE ('FRESH FEED')
C              STREAM 2:  CYCLONE FEED
C              STREAM 3:  CYCLONE OVERFLOW  (FLOTATION FEED)
C              STREAM 4:  CYCLONE UNDERFLOW (BALL MILL FEED)
C              STREAM 5:  BALL MILL DISCHARGE
C
C       THE FOLLOWING TERMS REFER TO THE ABOVE DEFINED STREAMS:
C
C       M1T TO M5T        TOTAL SOLIDS MASS FLOW RATE
C                         (UNITS/MIN)
C       PCTS1 TO PCTS5    PERCENT SOLIDS OF PULP
C       F1(I) TO F5(I)    SIZE ASSAYS OF SOLIDS
C       FF1(I) TO FF5(I)     CUMULATIVE WEIGHT PERCENT FINER
C       R1(I) TO R5(I)       CUMULATIVE MINERAL UNITS COARSER
C                            (UNITS/MIN)
C       Z1(I,J) TO Z5(I,J)  PERCENT MINERAL FREQUENCY DISTRIBUTION
C       ZF1(I,J) TO ZF5(I,J)  CUMULATIVE MINERAL DISTRIBUTION
C                             COARSER  (UNITS/MIN)
C       FM1(I,J) TO FM5(I,J)  CUMULATIVE MINERAL DISTRIBUTION
C                             FINER  (UNITS/MIN)
C
C
C
      CHARACTER*7 ELEM(4)
      DIMENSION F1(10),F2(10),F3(10),F4(10),F5(10),F1U(10)
      DIMENSION FF1(10),FF2(10),FF3(10),FF4(10),FF5(10)
      DIMENSION F1MU(10,4),F2MU(10,4),F3MU(10,4),F4MU(10,4),F5MU(10,4)
      DIMENSION F1MUC(10,4),F2MUC(10,4),F3MUC(10,4),F4MUC(10,4)
      DIMENSION F5MUC(10,4),CLMIN(4)
      DIMENSION F1CHEM(10,3),Y(10,4),B(9,4),P(9,4)
      DIMENSION V(4),RHO(4),RHOU(4),MESH(10),LAPERT(10),FACTOR(3)
      DIMENSION R1(10),R2(10),R3(10),R4(10),R5(10)
      DIMENSION Z1(10,4),Z2(10,4),Z3(10,4),Z4(10,4),Z5(10,4)
      DIMENSION ZF1(10,4),ZF2(10,4),ZF3(10,4),ZF4(10,4),ZF5(10,4)
      DIMENSION FM1(10,4),FM2(10,4),FM3(10,4),FM4(10,4),FM5(10,4)
      DIMENSION FG(4),YC(10,4)
```

CONTINUED ......

```
      DIMENSION D(10),D50C(4),YP(10,4)
      DIMENSION V2(4)
      REAL K1,K2,KL1,KL2,KL3,KL4,KL5,KL6,KL7,KL8,KL9,N,INLET
      REAL M1T,M2T,M3T,M4T,M5T,K(9,4)
      READ(5,1)BWH,SOL1
      READ(5,2)(RHO(I),I=1,4)
      READ(5,3)(MESH(I),I=1,10)
      READ(5,4)(LAPERT(I),I=1,10)
      READ(5,5)(FACTOR(I),I=1,3)
      READ(5,6)(F1(I),I=1,10)
      READ(5,7)((F1CHEM(I,J),I=1,10),J=1,3)
      READ(5,9)((P(I,J),I=1,9),J=1,4)
      READ(5,9)((B(I,J),I=1,9),J=1,4)
      READ(5,8)(ELEN(I),I=1,4)
      READ(5,12)(D(I),I=1,10)
    1 FORMAT(F8.6,1X,F5.1)
    2 FORMAT(4F4.2)
    3 FORMAT(10I4)
    4 FORMAT(I3,9(1X,I3))
    5 FORMAT(3(1X,F4.2))
    6 FORMAT(10F5.2)
    7 FORMAT(10F5.2)
    8 FORMAT(4A7)
    9 FORMAT(9(1X,F6.4))
   12 FORMAT(10F5.1)
C
C     DEFINITION OF PARAMETERS TO BE CONSTANT
C     THROUGH THE ITERATIVE PROCESS
C
      K1= -1.367
      N= 2.361
      VF= 15.24
      SPIG= 8.89
      INLET= 15.24
      KL1= 193.
      KL2= -271.6
      KL3= 17.08
      KL4= 0.04
      KL5= -0.0576
      KL6= 0.0366
      KL7= 0.0299
      KL8= -0.00005
      KL9= -0.0688
      FG(1)= 0.70
      FG(2)= 1.00
      FG(3)= 1.
      FG(4)= 1.00
C
      PCTS1= 77.
      RF= 34.
      VW1= (100.*SOL1/PCTS1 - SOL1)/60.
      VWS= 210./60.
      TON= 6.E5/SOL1
      UNIT= 1./TON
      M1T= 1.E4
      DO 10 I=1,4
      RHOU(I)= TON*RHO(I)
   10 CONTINUE
```

CONTINUED ......

```
      DO 20 J=1,3
      A= 0.0
      DO 20 I=1,10
      F1MU(I,J)= F1(I)*F1CHEM(I,J)*FACTOR(J)
      F1MUC(I,J)= A + F1MU(I,J)
      A= F1MUC(I,J)
   20 CONTINUE
      A= 0.0
      DO 30 I=1,10
      F1MU(I,4)= 100.*F1(I) - (F1MU(I,1)+F1MU(I,2)+F1MU(I,3))
      F1MUC(I,4)= A + F1MU(I,4)
      A= F1MUC(I,4)
   30 CONTINUE
      DO 40 J=1,4
      DO 40 I=1,10
      F5MU(I,J)= 0.0
   40 CONTINUE
      VW5= 0.0
C
C     BEGINNING OF THE ITERATIVE PROCESS
C
      M= 1
   15 DO 50 J=1,4
C
C
C
C     SUMP
C
C
      A= 0.0
      DO 50 I=1,10
      F2MU(I,J)= F1MU(I,J) + F5MU(I,J)
      F2MUC(I,J)= A + F2MU(I,J)
      A= F2MUC(I,J)
   50 CONTINUE
      VW2= VW1 + VW5
      DO 52 I=1,10
      A= 0.0
      B1= 0.0
      DO 52 J=1,4
      F1U(I)= A + F1MUC(I,J)
      F2(I)= B1 + F2MUC(I,J)
      A= F1U(I)
      B1= F2(I)
   52 CONTINUE
      A= 0.0
      DO 55 I=1,4
      M2T= A + F2MUC(10,I)
      A= M2T
   55 CONTINUE
      PCTS2= 100.*UNIT*M2T/(UNIT*M2T + VW2)
      DO 57 I=1,10
      FF1(I)= 100.*(M1T - F1U(I))/M1T
      FF2(I)= 100.*(M2T - F2(I))/M2T
   57 CONTINUE
C
C
C     CYCLONE
```

CONTINUED ......

```
C
C
      RF= KL1*SPIG/VW2/20. + KL2/VW2/20. + KL3
      VW4= RF*VW2/100.
      DO 61 I=1,4
      V2(I)= F2MUC(10,I)/RHOU(I)
 61   CONTINUE
      VT2= V2(1) + V2(2) + V2(3) + V2(4)
      Q= (VT2 + VW2)*1000./3.
      D50C(4)= 10.**(KL4*VF + KL5*SPIG + KL6*INLET + KL7*PCTS2 + KL8*Q
     a          + KL9)
      K2= ALOG(D50C(4)) - K1*ALOG(RHO(4) - 1.)
      DO 63 I=1,3
      D50C(I)= EXP(K1*ALOG(RHO(I) - 1.) + K2)
 63   CONTINUE
      DO 62 J=1,4
      Y(10,J)= RF
      DO 62 I=1,9
      X= D(I)/D50C(J)
      IF(X.GE.2.5)GO TO 21
      YP(I,J)= 100.*(1. - EXP(-0.693*X**N))
      GO TO 22
 21   YP(I,J)= 100.
 22   Y(I,J)= (100. - RF)*YP(I,J)/100. + RF
 62   CONTINUE
      DO 60 J=1,4
      A= 0.0
      B1= 0.0
      DO 60 I=1,10
      F4MU(I,J)= Y(I,J)*F2MU(I,J)/100.
      F3MU(I,J)= F2MU(I,J) - F4MU(I,J)
      F4MUC(I,J)= A + F4MU(I,J)
      F3MUC(I,J)= B1 + F3MU(I,J)
      A= F4MUC(I,J)
      B1= F3MUC(I,J)
 60   CONTINUE
      B1= 0.0
      C= 0.0
      DO 70 J=1,4
      V(J)= F4MUC(10,J)/RHOU(J)
      M3T= B1 + F3MUC(10,J)
      M4T= C + F4MUC(10,J)
      B1= M3T
      C= M4T
 70   CONTINUE
      SOL4= M4T*UNIT
      WADD= VW5 - VW4
C
C
C     BALL MILL
C
C
      VT= V(1) + V(2) + V(3) + V(4)
      RHOT= UNIT*M4T/VT
      TIME= BMH/(VW4 + VT)
      DO 80 J=1,4
      DO 80 I=1,9
      F5MUC(I,J)= F4MUC(I,J)*EXP(-FG(J)*B(I,J)*TIME**P(I,J))
```

CONTINUED ......

```
   80  CONTINUE
       DO 90 J=1,4
       F5MUC(10,J)= F4MUC(10,J)
       F5MU(1,J)= F5MUC(1,J)
   90  CONTINUE
       A= 0.0
       DO 95 J=1,4
       M5T= A + F5MUC(10,J)
       A= M5T
   95  CONTINUE
       DO 100 J=1,4
       DO 100 I=2,10
       L= I - 1
       F5MU(I,J)= F5MUC(I,J) - F5MUC(L,J)
  100  CONTINUE
       VW3= VW2 - VW4
C
       DO 110 I=1,10
       C= 0.0
       D1= 0.0
       E= 0.0
       R1(I)= 0.0
       R2(I)= 0.0
       R3(I)= 0.0
       R4(I)= 0.0
       R5(I)= 0.0
C
       DO 110 J=1,4
       F3(I)= C + F3MUC(I,J)
       F4(I)= D1 + F4MUC(I,J)
       F5(I)= E + F5MUC(I,J)
       R1(I)= R1(I) + F1MU(I,J)
       R2(I)= R2(I) + F2MU(I,J)
       R3(I)= R3(I) + F3MU(I,J)
       R4(I)= R4(I) + F4MU(I,J)
       R5(I)= R5(I) + F5MU(I,J)
       C= F3(I)
       D1= F4(I)
       E= F5(I)
  110  CONTINUE
       DO 120 I=1,10
       FF1(I)= 100.*(M1T - F1U(I))/M1T
       FF2(I)= 100.*(M2T - F2(I))/M2T
       FF3(I)= 100.*(M3T - F3(I))/M3T
       FF4(I)= 100.*(M4T - F4(I))/M4T
       FF5(I)= 100.*(M5T - F5(I))/M5T
  120  CONTINUE
       DO 130 J=1,4
       CLMIN(J)= 100.*F4MUC(10,J)/F1MUC(10,J)
  130  CONTINUE
       CLOV= 100.*M4T/M1T
       PCTS3= 100.*UNIT*M3T/(UNIT*M3T + VW3)
       PCTS4= 100.*UNIT*M4T/(UNIT*M4T + VW4)
       PCTS5= PCTS4
       A= ABS(M1T - M3T)
C
C
C
```

CONTINUED ......

```
C    CONVERGENCE TEST OF STEADY STATE MASS FLOW CONDITIONS
C
C
      IF((A.LE.10.).OR.(M.EQ.50))GO TO 140
      M= M+1
      GO TO 15
C
C
C     END OF ITERATIVE PROCESS
C
 140  DO 145 J=1,4
      S1= 0.0
      S2= 0.0
      S3= 0.0
      S4= 0.0
      S5= 0.0
      DO 145 I=1,10
      Z1(I,J)= 100.*F1MU(I,J)/F1MUC(10,J)
      Z2(I,J)= 100.*F2MU(I,J)/F2MUC(10,J)
      Z3(I,J)= 100.*F3MU(I,J)/F3MUC(10,J)
      Z4(I,J)= 100.*F4MU(I,J)/F4MUC(10,J)
      Z5(I,J)= 100.*F5MU(I,J)/F5MUC(10,J)
      ZF1(I,J)= S1 + Z1(I,J)
      ZF2(I,J)= S2 + Z2(I,J)
      ZF3(I,J)= S3 + Z3(I,J)
      ZF4(I,J)= S4 + Z4(I,J)
      ZF5(I,J)= S5 + Z5(I,J)
      FM1(I,J)= 100. - ZF1(I,J)
      FM2(I,J)= 100. - ZF2(I,J)
      FM3(I,J)= 100. - ZF3(I,J)
      FM4(I,J)= 100. - ZF4(I,J)
      FM5(I,J)= 100. - ZF5(I,J)
      S1= ZF1(I,J)
      S2= ZF2(I,J)
      S3= ZF3(I,J)
      S4= ZF4(I,J)
      S5= ZF5(I,J)
 145  CONTINUE
      DO 199 J=1,4
      DO 199 I=1,10
      YC(I,J)= 100.*YC(I,J)
 199  CONTINUE
      WRITE(6,310)SOL1,BMH,(FG(I),I=1,4)
      DO 301 I=1,9
      WRITE(6,315)MESH(I),F1(I),(F1CHEM(I,J),J=1,3),(B(I,J),J=1,4),(P(I,
     @J),J=1,4)
 301  CONTINUE
 310  FORMAT('1'//' ',15X,'INPUT DATA USED IN SIMULATING A PB-ZN ORE GRI
     @NDING OPERATION'//' ',15X,'FLOW RATE INPUT (FRESH FEED):',F10.2,'
     @METRIC TONS PER HOUR'/' ',15X,'BALL MILL HOLDUP:',16X,F6.2,' CUBIC
     @ METERS'//' ',15X,'GRINDING SCALE FACTOR FOR PBS:',F10.2//' ',15X,
     @'GRINDING SCALE FACTOR FOR ZNS:',F10.2//' ',15X,
     @'GRINDING SCALE FACTOR FOR FES2:',F9.2//' ',15X,
     @'GRINDING SCALE FACTOR FOR CAL/DOL:',F6.2/////' ',15X,
     @'MESH',3X,'SIZE',3X,'CHEMICAL  ASSAYS',5X,'SPECIFIC RATE OF BREAKA
     @GE',7X,'P  ORDER OF BREAKAGE'/' ',16X,'NO',3X,'ASSAYS',4X,'PB',4X,
     @'ZN',4X,'FE',10X,'PBS',3X,'ZNS',2X,'FES2 CAL/DOL',4X,'PBS',4X,
     @'ZNS',2X,'FES2 CAL/DOL'//)
```

CONTINUED ......

```
 315   FORMAT(' ',15X,I4,2X,F6.2,1X,3F6.2,3X,4F7.4,2X,4F7.4)
       WRITE(6,316)MESH(10),FI(10),(FICHEM(10,J),J=1,3)
 316   FORMAT(' ',15X,I4,2X,F6.2,1X,3F6.2)
       WRITE(6,700)(D50C(I),I=1,4)
 700   FORMAT(///15X,'THE CORRECTED D50C VALUES ARE:'//20X,'PBS:',F12.2/
      @20X,'ZNS:',F12.2/20X,'FES2:',F11.2/20X,'CAL/DOL:',F8.2)
       WRITE(6,200)M,RHOT,TIME,CLOV,(CLMIN(J),J=1,4),PCTS1,PCTS2,PCTS3,
      @PCTS4,PCTS5
 200   FORMAT('1'///' ',22X,'ITERATION:',I3,18X,'SP. GR. BALL MILL FEED:'
      @,F5.2/' ',22X,'RESIDENCE TIME:',F5.2,' MIN',11X,'TOTAL CIRC. LOAD:
      @',F7.2//' ',31X,'PBS C.L.  ',F6.2,11X,'ZNS C.L. ',F6.2/' ',
      @31X,'FES2 C.L. ',F6.2,7X,'CAL/DOL C.L. ',F6.2//' ',31X,
      @'PCT SOLIDS BY WT. STREAM NO ONE:',F9.2/' ',31X,
      @'PCT SOLIDS BY WT. STREAM NO TWO:',F9.2/' ',31X,'PCT SOLIDS BY WT.
      @ STREAM NO THREE:',F7.2/' ',31X,'PCT SOLIDS BY WT. STREAM NO FOUR:
      @',F8.2/' ',31X,'PCT SOLIDS BY WT. STREAM NO FIVE:',F8.2///' ',
      @'CUMULATIVE WT PCT FINER - OVERALL'///)
       WRITE(6,210)
 210   FORMAT(' ',14X,'MESH',4X,'SIZE'/' ',15X,'NO',5X,'MICR',3X,
      @'STREAM 1',1X,'STREAM 2',1X,'STREAM 3',1X,'STREAM 4',1X,'STREAM 5'
      @)
       DO 220 I=1,9
       WRITE(6,250)MESH(I),LAPERT(I),FF1(I),FF2(I),FF3(I),FF4(I),FF5(I)
 250   FORMAT(' ',14X,I4,5X,I3,5(3X,F6.2)//)
 220   CONTINUE
       J1= 1
       J2= 2
       J3= 3
       J4= 4
       J5= 5
       WRITE(6,255)J1
       DO 146 I=1,10
       WRITE(6,260)MESH(I),LAPERT(I),R1(I),(F1MU(I,J),J=1,4)
 146   CONTINUE
       WRITE(6,255)J2
       DO 150 I=1,10
       WRITE(6,260)MESH(I),LAPERT(I),R2(I),(F2MU(I,J),J=1,4)
  150   CONTINUE
       WRITE(6,255)J3
       DO 160 I=1,10
       WRITE(6,260)MESH(I),LAPERT(I),R3(I),(F3MU(I,J),J=1,4)
 160   CONTINUE
       WRITE(6,255)J4
       DO 170 I=1,10
       WRITE(6,260)MESH(I),LAPERT(I),R4(I),(F4MU(I,J),J=1,4)
 170   CONTINUE
       WRITE(6,255)J5
       DO 180 I=1,10
       WRITE(6,260)MESH(I),LAPERT(I),R5(I),(F5MU(I,J),J=1,4)
 180   CONTINUE
 255   FORMAT('1'////,22X,'MINERAL UNITS RETAINED',10X,'STREAM NO: ',
      @I2//' ',22X,'MESH',4X,'SIZE'/' ',23X,'NO',5X,'MICR',5X,'OVERALL',
      @5X,'PBS',6X,'ZNS',5X,'FES2',3X,'CAL/DOL'/)
 260   FORMAT(' ',22X,I4,5X,I3,3X,5F9.2//)
       WRITE(6,265)J1
       DO 181 I=1,10
       WRITE(6,270)MESH(I),LAPERT(I),(Z1(I,J),J=1,4)
 181   CONTINUE
```

CONTINUED ......

```
      WRITE(6,265)J2
      DO 182 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z2(I,J),J=1,4)
  182 CONTINUE
      WRITE(6,265)J3
      DO 183 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z3(I,J),J=1,4)
  183 CONTINUE
      WRITE(6,265)J4
      DO 184 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z4(I,J),J=1,4)
  184 CONTINUE
      WRITE(6,265)J5
      DO 185 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z5(I,J),J=1,4)
  185 CONTINUE
  265 FORMAT('1'////' ',22X,'MINERAL DISTRIBUTION, PCT',7X,'STREAM NO: '
     @,I2//' ',22X,'MESH',4X,'SIZE'/' ',23X,'NO',5X,'MICR',5X,'PBS',
     @6X,'ZNS',4X,'FES2',4X,'CAL/DOL'/)
  270 FORMAT(' ',22X,I4,5X,I3,5(3X,F6.2)//)
      WRITE(6,275)J1
      DO 191 I=1,9
      WRITE(6,280)MESH(I),LAPERT(I),(FM1(I,J),J=1,4)
  191 CONTINUE
      WRITE(6,275)J2
      DO 192 I=1,9
      WRITE(6,280)MESH(I),LAPERT(I),(FM2(I,J),J=1,4)
  192 CONTINUE
      WRITE(6,275)J3
      DO 193 I=1,9
      WRITE(6,280)MESH(I),LAPERT(I),(FM3(I,J),J=1,4)
  193 CONTINUE
      WRITE(6,275)J4
      DO 194 I=1,9
      WRITE(6,280)MESH(I),LAPERT(I),(FM4(I,J),J=1,4)
  194 CONTINUE
      WRITE(6,275)J5
      DO 195 I=1,9
      WRITE(6,280)MESH(I),LAPERT(I),(FM5(I,J),J=1,4)
  195 CONTINUE
  275 FORMAT('1'////' ',22X,'CUM MINERAL PCT FINER',3X,'STREAM NO: ',
     @I2//' ',22X,'MESH',4X,'SIZE',/' ',23X,'NO',5X,'MICR',5X,'PBS',
     @6X,'ZNS',4X,'FES2',4X,'CAL/DOL'/)
  280 FORMAT(' ',22X,I4,5X,I3,5(3X,F6.2)//)
C
C
C     CALCULATING THE INSTANTANEOUS RATE-OF-BREAKAGE
C
C
      DO 147 J=1,4
      DO 147 I=1,9
      K(I,J)= B(I,J)*TIME**(P(I,J) - 1.)*FG(J)
  147 CONTINUE
      WRITE(6,303)
      DO 196 I=1,9
      WRITE(6,304)MESH(I),LAPERT(I),(K(I,J),J=1,4)
  196 CONTINUE
  303 FORMAT('1'////' ',15X,'INSTANTANEOUS RATES OF BREAKAGE AT THE TIME
```

CONTINUED ......

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     @'/' ',57X,'-1'/' ',15X,'STEADY STATE CONDITIONS WERE REACHED. MIN'
     @//' ',15X,'MESH',4X,'SIZE'/' ',16X,'NO',5X,'MICR',5X,'PHS',6X,'ZNS
     @',5X,'FES2',4X,'CAL/DOL'/)
 304  FORMAT(' ',15X,I4,5X,I3,4(4X,F5.3)//)
      STOP
      END
$DATA
C
C ... DATA CARDS
C
$
```

INPUT DATA USED IN SIMULATING A PB-ZN ORE GRINDING OPERATION

FLOW RATE INPUT (FRESH FEED): 154.20 METRIC TONS PER HOUR
BALL MILL HOLDUP: 8.37 CUBIC METERS

GRINDING SCALE FACTOR FOR PBS: 0.70

GRINDING SCALE FACTOR FOR ZNS: 1.00

GRINDING SCALE FACTOR FOR FES2: 1.00

GRINDING SCALE FACTOR FOR CAL/DOL: 1.00

MESH NO	SIZE ASSAYS	CHEMICAL ASSAYS PB	ZN	FE	SPECIFIC RATE OF BREAKAGE PBS	ZNS	FES2	CAL/DOL	P ORDER OF BREAKAGE PBS	ZNS	FES2	CAL/DOL
28	19.42	1.48	4.99	10.23	0.9141	0.7581	0.6797	0.6840	0.7483	0.8145	0.6452	0.8773
35	7.96	1.25	6.01	6.95	0.8155	0.6548	0.4826	0.5842	0.7852	0.9210	0.8653	0.9973
48	7.39	2.17	7.49	8.35	0.5981	0.4711	0.3380	0.3730	0.9831	1.0460	0.9808	1.1673
65	5.72	1.40	5.19	5.97	0.3948	0.3164	0.2430	0.2779	1.1088	1.0765	0.9803	1.1622
100	7.62	2.94	8.45	6.76	0.2708	0.1808	0.1329	0.1725	1.0421	1.0457	0.9213	1.1588
150	9.06	1.55	5.22	4.46	0.1615	0.0990	0.0601	0.1631	1.0365	1.0890	1.2340	0.9272
200	8.16	1.37	4.94	4.01	0.1085	0.0737	0.0476	0.0934	0.9679	0.9770	1.0694	1.0294
270	8.66	1.59	5.54	4.40	0.0813	0.0408	0.0314	0.0573	0.7736	1.0535	1.0053	1.0865
400	5.38	1.64	5.62	4.45	0.0595	0.0318	0.0239	0.0444	0.7825	1.0498	1.0511	1.0577
-400	20.66	1.59	6.00	5.88								

MESH NO	CYCLONE SELEC INDEX, Y PB	ZN	FE	CAL/DOL
28	100.00	100.00	100.00	100.00
35	100.00	100.00	100.00	99.49
48	100.00	100.00	100.00	92.29
65	100.00	99.52	100.00	74.43
100	100.00	92.49	99.73	56.65
150	100.00	74.96	94.32	45.22
200	99.61	56.77	77.38	39.16
270	93.00	45.15	58.68	36.31
400	75.69	39.22	46.42	35.04
-400	34.00	34.00	34.00	34.00

THE CORRECTED D50C VALUES ARE:

PBS:	37.69
ZNS:	108.46
FES2:	73.19
CAL/DOL:	218.04

ITERATION: 18 SP. GR. BALL MILL FEED: 3.56
RESIDENCE TIME: 3.10 MIN TOTAL CIRC. LOAD: 172.50

PBS C.L. 552.25 ZNS C.L. 206.56
FES2 C.L. 400.60 CAL/DOL C.L. 116.03

PCT SOLIDS BY WT. STREAM NO ONE: 77.00
PCT SOLIDS BY WT. STREAM NO TWO: 62.13
PCT SOLIDS BY WT. STREAM NO THREE: 47.69
PCT SOLIDS BY WT. STREAM NO FOUR: 75.34
PCT SOLIDS BY WT. STREAM NO FIVE: 75.34

CUMULATIVE WT PCT FINER - OVERALL

MESH NO	SIZE MICR	STREAM 1	STREAM 2	STREAM 3	STREAM 4	STREAM 5
28	592	80.58	91.32	100.00	86.29	97.55
35	419	72.62	87.60	99.96	80.43	96.28
48	296	65.23	82.62	99.27	72.97	92.70
65	209	59.51	76.67	96.53	65.17	86.63
100	148	51.89	63.71	88.71	49.24	70.59
150	105	42.84	50.20	77.40	34.44	54.47
200	74	34.68	37.67	62.45	23.31	39.40
270	53	26.02	26.43	46.57	14.76	26.65
400	37	20.64	20.77	37.38	11.15	20.83

MINERAL DISTRIBUTION, PCT STREAM NO: 1

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	17.34	16.60	30.19	17.77
35	419	6.00	8.19	8.41	7.90
48	296	9.67	9.48	9.38	6.71
65	209	4.83	5.08	5.19	5.91
100	148	13.51	11.03	7.83	7.04
150	105	8.46	8.09	6.13	9.72
200	74	6.74	6.90	4.97	8.94
270	53	8.31	8.22	5.79	9.26
400	37	5.32	5.18	3.64	5.73
-400	-37	19.81	21.23	18.46	21.02

MINERAL DISTRIBUTION, PCT STREAM NO: 2

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	3.45	6.35	7.99	9.76
35	419	1.35	3.22	2.68	4.44
48	296	2.27	4.64	4.28	5.54
65	209	2.33	5.28	5.43	6.55
100	148	7.80	15.81	18.27	10.57
150	105	12.87	17.26	19.10	10.52
200	74	19.29	11.77	14.19	11.42
270	53	24.91	11.00	10.30	10.65
400	37	9.63	5.04	3.57	6.37
-400	-37	16.10	19.62	14.20	24.18

MINERAL DISTRIBUTION, PCT STREAM NO: 3

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	0.00	0.00	0.00	0.00
35	419	0.00	0.00	0.00	0.05
48	296	0.00	0.00	0.00	0.92
65	209	0.00	0.08	0.00	3.62
100	148	0.00	3.63	0.25	9.92
150	105	0.00	13.23	5.46	12.45
200	74	0.51	15.57	16.15	15.01
270	53	11.79	18.47	21.40	14.65
400	37	15.84	9.38	9.61	8.93
-400	-37	71.86	39.63	47.13	34.46

MINERAL DISTRIBUTION, PCT STREAM NO: 4

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	4.05	9.44	9.97	18.18
35	419	1.58	4.78	3.35	8.23
48	296	2.67	6.90	5.35	9.53
65	209	2.74	7.81	6.77	9.08
100	148	9.16	21.72	22.75	11.13
150	105	15.10	19.21	22.48	8.86
200	74	22.55	9.92	13.71	8.33
270	53	27.19	7.38	7.54	7.20
400	37	8.55	2.94	2.07	4.15
-400	-37	6.42	9.91	6.02	15.31

MINERAL DISTRIBUTION, PCT STREAM NO: 5

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	0.91	1.40	2.43	2.87
35	419	0.49	0.82	1.25	1.47
48	296	0.92	2.31	3.01	4.54
65	209	1.86	5.39	5.48	7.10
100	148	6.71	18.13	20.87	13.61
150	105	13.59	21.68	22.37	11.21
200	74	21.60	14.11	16.50	13.56
270	53	28.09	12.34	11.42	11.85
400	37	10.42	4.97	3.55	6.91
-400	-37	15.42	18.84	13.13	26.90

CUM MINERAL PCT FINER STREAM NO: 1

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	82.66	83.40	69.81	82.23
35	419	76.66	75.21	61.40	74.33
48	296	66.99	65.73	52.02	67.62
65	209	62.16	60.65	46.83	61.71
100	148	48.65	49.62	39.00	54.67
150	105	40.18	41.53	32.87	44.95
200	74	33.44	34.62	27.89	36.01
270	53	25.14	26.41	22.10	26.75
400	37	19.81	21.23	18.46	21.02

CUM MINERAL PCT FINER STREAM NO: 2

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	96.55	93.65	92.01	90.24
35	419	95.20	90.43	89.33	85.80
48	296	92.93	85.78	85.05	80.25
65	209	90.60	80.50	79.62	73.70
100	148	82.83	64.69	61.35	63.13
150	105	69.93	47.43	42.25	52.61
200	74	50.64	35.66	28.06	41.19
270	53	25.73	24.66	17.76	30.54
400	37	16.10	19.62	14.20	24.18

CUM MINERAL PCT FINER STREAM NO: 3

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	100.00	100.00	100.00	100.00
35	419	100.00	100.00	100.00	99.95
48	296	100.00	100.00	100.00	99.03
65	209	100.00	99.92	100.00	95.41
100	148	100.00	96.29	99.75	85.49
150	105	100.00	83.06	94.29	73.05
200	74	99.49	67.48	78.14	58.04
270	53	87.70	49.01	56.74	43.39
400	37	71.86	39.63	47.13	34.46

CUM MINERAL PCT FINER STREAM NO: 4

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	95.95	90.56	90.03	81.82
35	419	94.37	85.78	86.68	73.59
48	296	91.70	78.89	81.34	64.06
65	209	88.97	71.08	74.56	54.98
100	148	79.81	49.36	51.82	43.85
150	105	64.71	30.15	29.34	34.99
200	74	42.16	20.22	15.63	26.66
270	53	14.97	12.84	8.09	19.46
400	37	6.42	9.91	6.02	15.31

CUM MINERAL PCT FINER STREAM NO: 5

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	99.09	98.60	97.57	97.13
35	419	98.60	97.78	96.32	95.67
48	296	97.68	95.48	93.31	91.13
65	209	95.82	90.09	87.84	84.03
100	148	89.11	71.96	66.96	70.42
150	105	75.52	50.27	44.59	59.22
200	74	53.92	36.16	28.09	45.66
270	53	25.84	23.82	16.67	33.81
400	37	15.42	18.84	13.13	26.90

INSTANTANEOUS RATES OF BREAKAGE AT THE TIME STEADY STATE CONDITIONS WERE REACHED, MIN^{-1}

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	0.481	0.614	0.455	0.595
35	419	0.448	0.599	0.414	0.582
48	296	0.411	0.496	0.331	0.451
65	209	0.313	0.345	0.238	0.334
100	148	0.199	0.190	0.122	0.206
150	105	0.118	0.110	0.078	0.150
200	74	0.073	0.072	0.051	0.097
270	53	0.044	0.043	0.032	0.063
400	37	0.033	0.034	0.025	0.047

V.2.2 Results at 190.3 mtph

INPUT DATA USED IN SIMULATING A PB-ZN ORE GRINDING OPERATION

FLOW RATE INPUT (FRESH FEED): 190.30 METRIC TONS PER HOUR
BALL MILL HOLDUP: 8.37 CUBIC METERS

GRINDING SCALE FACTOR FOR PBS: 0.70

GRINDING SCALE FACTOR FOR ZNS: 1.00

GRINDING SCALE FACTOR FOR FES2: 1.00

GRINDING SCALE FACTOR FOR CAL/DOL: 1.00

MESH NO	SIZE ASSAYS	CHEMICAL ASSAYS PB	ZN	FE	SPECIFIC RATE OF BREAKAGE PBS	ZNS	FES2	CAL/DOL	P ORDER OF BREAKAGE PBS	ZNS	FES2	CAL/DOL
28	24.24	1.44	4.68	4.71	0.9141	0.7581	0.6797	0.6840	0.7483	0.8145	0.6452	0.8773
35	5.94	2.32	5.82	3.71	0.8155	0.6548	0.4826	0.5842	0.7852	0.9210	0.8653	0.9973
48	6.31	2.75	6.11	3.83	0.5981	0.4711	0.3380	0.3730	0.9831	1.0460	0.9808	1.1673
65	6.10	0.43	3.77	2.04	0.3948	0.3164	0.2430	0.2779	1.1088	1.0765	0.9803	1.1622
100	10.20	1.58	3.63	1.84	0.2708	0.1808	0.1329	0.1725	1.0421	1.0457	0.9213	1.1588
150	10.33	1.62	3.61	1.93	0.1615	0.0990	0.0601	0.1631	1.0365	1.0890	1.2340	0.9272
200	8.12	1.28	3.49	1.66	0.1085	0.0737	0.0476	0.0934	0.9679	0.9770	1.0694	1.0294
270	7.47	1.25	4.05	1.73	0.0813	0.0408	0.0314	0.0573	0.7736	1.0535	1.0053	1.0865
400	3.89	1.81	3.99	2.00	0.0595	0.0318	0.0239	0.0444	0.7825	1.0498	1.0511	1.0577
-400	17.41	1.78	4.80	2.84								

MESH NO	CYCLONE SELEC INDEX, Y PB	ZN	FE	CAL/DOL
28	100.00	100.00	100.00	100.00
35	100.00	100.00	100.00	100.00
48	100.00	100.00	100.00	96.96
65	100.00	100.00	100.00	82.44
100	100.00	97.08	100.00	61.85
150	100.00	82.96	98.06	46.45
200	100.00	62.13	85.32	37.56
270	97.36	46.35	64.56	33.24
400	83.69	37.65	48.15	31.28
-400	29.67	29.67	29.67	29.67

THE CORRECTED D50C VALUES ARE:

PBS: 32.08
ZNS: 92.31
FES2: 62.29
CAL/DOL: 185.57

ITERATION: 23
RESIDENCE TIME: 2.43 MIN

SP. GR. BALL MILL FEED: 3.3[illegible]
TOTAL CIRC. LOAD: 183.16

PBS C.L. 728.28
FES2 C.L. 565.79

ZNS C.L. 279.80
CAL/DOL C.L. 135.49

PCT SOLIDS BY WT. STREAM NO ONE: 78.80
PCT SOLIDS BY WT. STREAM NO TWO: 61.01
PCT SOLIDS BY WT. STREAM NO THREE: 43.99
PCT SOLIDS BY WT. STREAM NO FOUR: 77.34
PCT SOLIDS BY WT. STREAM NO FIVE: 77.34

CUMULATIVE WT PCT FINER – OVERALL

MESH NO	SIZE MICR	STREAM 1	STREAM 2	STREAM 3	STREAM 4	STREAM 5
28	592	75.76	88.83	100.00	82.74	95.97
35	419	69.82	85.69	100.00	77.88	94.36
48	296	63.51	80.03	99.61	69.35	89.06
65	209	57.41	72.71	96.69	59.63	81.08
100	148	47.21	57.76	85.23	42.77	63.55
150	105	36.88	43.78	72.51	28.11	47.57
200	74	28.76	31.33	56.07	17.83	32.75
270	53	21.29	21.20	40.93	10.45	21.15
400	37	17.40	16.60	33.07	7.61	16.15

MINERAL DISTRIBUTION, PCT STREAM NO: 1

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	21.92	25.69	38.68	23.10
35	419	8.65	7.83	7.47	5.62
48	296	10.89	8.73	8.19	5.88
65	209	1.65	5.21	4.22	6.40
100	148	10.12	8.39	6.36	10.63
150	105	10.51	8.45	6.75	10.74
200	74	6.53	6.42	4.57	8.55
270	53	5.86	6.85	4.38	7.78
400	37	4.42	3.52	2.64	4.00
-400	-37	19.46	18.93	16.75	17.30

MINERAL DISTRIBUTION, PCT STREAM NO: 2

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	3.74	8.55	8.31	12.65
35	419	1.70	2.85	2.43	3.44
48	296	2.51	4.55	4.02	6.37
65	209	2.06	6.30	5.25	8.28
100	148	6.99	16.90	17.50	14.77
150	105	14.27	21.03	24.84	10.80
200	74	19.81	11.57	14.92	11.49
270	53	25.23	9.88	9.39	9.18
400	37	10.79	3.62	2.91	4.62
-400	-37	12.90	14.74	10.44	18.40

MINERAL DISTRIBUTION, PCT STREAM NO: 3

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	0.00	0.00	0.00	0.00
35	419	0.00	0.00	0.00	0.00
48	296	0.00	0.00	0.00	0.46
65	209	0.00	0.00	0.00	3.42
100	148	0.00	1.87	0.00	13.27
150	105	0.00	13.58	3.25	13.61
200	74	0.00	16.61	14.75	16.88
270	53	5.79	20.09	22.40	14.42
400	37	15.31	8.56	10.14	7.48
-400	-37	78.91	39.28	49.45	30.46

MINERAL DISTRIBUTION, PCT STREAM NO: 4

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	4.23	11.61	9.76	22.00
35	419	1.92	3.88	2.85	5.98
48	296	2.84	6.18	4.72	10.74
65	209	2.33	8.56	6.17	11.86
100	148	7.90	22.29	20.55	15.89
150	105	16.12	23.70	28.61	8.72
200	74	22.39	9.77	14.95	7.50
270	53	27.75	6.22	7.12	5.30
400	37	10.20	1.85	1.64	2.51
-400	-37	4.32	5.94	3.64	9.49

MINERAL DISTRIBUTION, PCT STREAM NO: 5

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	1.22	2.43	2.92	4.95
35	419	0.74	1.08	1.53	1.83
48	296	1.34	3.06	3.27	6.74
65	209	2.10	6.70	5.42	9.66
100	148	6.51	19.96	19.44	17.83
150	105	14.69	25.51	28.10	10.84
200	74	21.64	13.40	16.77	13.65
270	53	28.09	10.96	10.27	10.21
400	37	11.68	3.66	2.95	5.08
-400	-37	11.99	13.24	9.32	19.21

CUM MINERAL PCT FINER STREAM NO: 1

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	78.08	74.31	61.32	76.90
35	419	69.43	66.48	53.85	71.28
48	296	58.54	57.75	45.66	65.39
65	209	56.89	52.54	41.45	58.99
100	148	46.77	44.16	35.09	48.36
150	105	36.27	35.71	28.33	37.63
200	74	29.74	29.29	23.77	29.08

CUM MINERAL PCT FINER STREAM NO: 2

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	96.26	91.45	91.69	87.35
35	419	94.56	88.60	89.27	83.91
48	296	92.04	84.05	85.25	77.53
65	209	89.98	77.75	80.00	69.26
100	148	82.99	60.84	62.50	54.48
150	105	68.73	39.81	37.66	43.69
200	74	48.91	28.24	22.73	32.20

CUM MINERAL PCT FINER STREAM NO: 3

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	100.00	100.00	100.00	100.00
35	419	100.00	100.00	100.00	100.00
48	296	100.00	100.00	100.00	99.54
65	209	100.00	100.00	100.00	96.12
100	148	100.00	98.13	100.00	82.85
150	105	100.00	84.54	96.75	69.24
200	74	100.00	67.93	81.99	52.36
270	53	94.21	47.85	59.60	37.94
400	37	78.91	39.28	49.45	30.46

CUM MINERAL PCT FINER STREAM NO: 4

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	95.77	88.39	90.24	78.30
35	419	93.85	84.51	87.39	72.02
48	296	91.01	78.33	82.67	61.28
65	209	88.68	69.77	76.51	49.42
100	148	80.78	47.48	55.96	33.53
150	105	64.66	23.78	27.35	24.81
200	74	42.28	14.01	12.40	17.31

CUM MINERAL PCT FINER STREAM NO: 5

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	98.78	97.57	97.08	95.05
35	419	98.05	96.49	95.55	93.22
48	296	96.70	93.43	92.28	86.48
65	209	94.60	86.73	86.85	76.82
100	148	88.39	66.78	67.42	58.99
150	105	73.40	41.26	39.31	48.16
200	74	51.76	27.86	22.55	34.50
270	53	23.67	16.90	12.28	24.30
400	37	11.99	13.24	9.32	19.21

INSTANTANEOUS RATES OF BREAKAGE AT THE TIME
STEADY STATE CONDITIONS WERE REACHED, MIN^{-1}

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	0.512	0.643	0.496	0.613
35	419	0.472	0.610	0.428	0.583
48	296	0.412	0.491	0.332	0.433
65	209	0.304	0.339	0.239	0.321
100	148	0.197	0.188	0.124	0.199
150	105	0.117	0.107	0.074	0.153
200	74	0.074	0.072	0.051	0.096
270	53	0.047	0.043	0.032	0.062
400	37	0.034	0.033	0.025	0.047

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C       COMPUTER PROGRAM TO SIMULATE A CLOSED GRINDING CIRCUIT
C
C
C       THE PROGRAM ITERATIVELY COMPUTES THE MINERAL FLOW RATES
C
C       THE PROGRAM SIMULATES A CLOSED GRINDING CIRCUIT IN
C       WHICH A PBS FLOTATION STAGE HAS BEEN INCORPORATED
C       DOWNSTREAMS OF THE BALL MILL
C
C
C       NOMENCLATURE
C       ------------
C       RHO(I)            SPECIFIC GRAVITY OF PURE MINERALS
C                         (MET TON/CUBIC METRE)
C                         RHO(1)= 7.50     (GALENA)
C                         RHO(2)= 5.00     (PYRITE)
C                         RHO(3)= 4.00     (SPHALERITE)
C                         RHO(4)= 2.85     (CALCITE-DOLOMITE)
C
C       RHOU(I)           SPECIFIC GRAVITY OF PURE MINERALS
C                         (UNITS/CUBIC METRE)
C       FACTOR(I)         STOICHIOMETRIC FACTOR FOR CONVERTING
C                         ELEMENT ASSAYS TO MINERAL ASSAYS
C                         FACTOR(1)= 1.15     (GALENA - PBS)
C                         FACTOR(2)= 1.48     (SPHALERITE - ZNS)
C                         FACTOR(3)= 2.15     (PYRITE - FES2)
C
C       TON               CONVERTION FACTOR  (METRIC TONNES TO
C                         MINERAL UNITS)
C       UNIT              CONVERTION FACTOR  (MINERAL UNITS TO
C                         METRIC TONNES)
C       BMH               VOLUMETRIC BALL MILL HOLDUP (CUBIC METRES)
C       TIME              BALL MILL RESIDENCE TIME (MINUTES)
C       P(I,J)            ORDER OF BREAKAGE (SIZE-BY-SIZE AND
C                         MINERAL-BY-MINERAL)
C       B(I,J)            CUMULATIVE-BASIS SPECIFIC RATE-OF-BREAKAGE
C       Y(I,J)            CYCLONE SELECTIVITY INDEX
C     YC(I,J)           FLOTATION RECOVERY
C      FICHEM(I,J)        SIZE-BY-SIZE ELEMENT ASSAYS OF ROD MILL
C                         DISCHARGE  (PERCENT)
C       FG(I)             GRIND SCALING FACTOR  (A FITTING PARAMETER)
C       K(I,J)            INSTANTANEOUS RATE-OF-BREAKAGE
C                         (SIZE-BY-SIZE AND MINERAL-BY-MINERAL)
C       CLOV              OVERALL CIRCULATING LOAD  (PERCENT)
C       CLMIN(I)          MINERAL CIRCULATING LOAD  (PERCENT)
C       WADD              MAKE-UP WATER ADDITION TO SUMP
C                         (CUBIC METRES/MIN)
C       V(I)              VOLUMETRIC MINERAL FLOW RATES IN BALL
C                         MILL FEED  (CUBIC METRE/MIN)
C       VT                TOTAL VOLUMETRIC OF SOLIDS IN BALL MILL
C                         FEED  (CUBIC METRE/MIN)
C
C
C       NOTE:   THE GRIND CIRCUIT CONTAINS EIGHT STREAMS
C               STREAM 1:  ROD MILL DISCHARGE ('FRESH FEED')
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CONTINUED ......

```
C              STREAM 2:   CYCLONE FEED
C              STREAM 3:   CYCLONE OVERFLOW
C                          (TO EXTERNAL PBS FLOTATION STAGES)
C              STREAM 4:   CYCLONE UNDERFLOW (BALL MILL FEED)
C              STREAM 5:   BALL MILL DISCHARGE
C                          (TO THE INCORPORATED FLOTATION STAGE)
C              STREAM 6:   CONCENTRATE OF INCORPORATED FLOTATION
C                          STAGE
C              STREAM 7:   TAILS OF INCORPORATED FLOTATION STAGE
C                          (TO THE SUMP)
C              STREAM 8:   STREAMS 3 + 6 (ONLY FOR COMPUTING
C                          PURPOSES)
C
C        THE FOLLOWING TERMS REFER TO THE ABOVE DEFINED STREAMS:
C
C        M1T TO M8T          TOTAL SOLIDS MASS FLOW RATE
C                            (UNITS/MIN)
C        PCTS1 TO PCTS8      PERCENT SOLIDS OF PULP
C        F1(I) TO F8(I)      SIZE ASSAYS OF SOLIDS
C        FF1(I) TO FF8(I)       CUMULATIVE WEIGHT PERCENT FINER
C        R1(I) TO R8(I)         CUMULATIVE MINERAL UNITS COARSER
C                               (UNITS/MIN)
C        Z1(I,J) TO Z8(I,J)  PERCENT MINERAL FREQUENCY DISTRIBUTION
C        ZF1(I,J) TO ZF8(I,J)  CUMULATIVE MINERAL DISTRIBUTION
C                              COARSER  (UNITS/MIN)
C        FM1(I,J) TO FM8(I,J)  CUMULATIVE MINERAL DISTRIBUTION
C                              FINER  (UNITS/MIN)
C
C
C
C
      CHARACTER*7 ELEM(4)
      DIMENSION F1(10),F2(10),F3(10),F4(10),F5(10),F1U(10)
      DIMENSION F6(10),F7(10),F8(10),FF6(10),FF7(10),FF8(10)
      DIMENSION FF1(10),FF2(10),FF3(10),FF4(10),FF5(10)
      DIMENSION F1MU(10,4),F2MU(10,4),F3MU(10,4),F4MU(10,4),E5MU(10,4)
      DIMENSION F6MU(10,4),F7MU(10,4),F8MU(10,4),F6MUC(10,4),F7MUC(10,4)
      DIMENSION F8MUC(10,4)
      DIMENSION F1MUC(10,4),F2MUC(10,4),F3MUC(10,4),F4MUC(10,4)
      DIMENSION F5MUC(10,4),CLMIN(4)
      DIMENSION FICHEM(10,3),Y(10,4),B(9,4),P(9,4)
      DIMENSION V(4),RHO(4),RHOU(4),MESH(10),LAPERT(10),FACTOR(3)
      DIMENSION R1(10),R2(10),R3(10),R4(10),R5(10)
      DIMENSION R6(10),R7(10),R8(10),Z6(10,4),Z7(10,4),Z8(10,4)
      DIMENSION Z1(10,4),Z2(10,4),Z3(10,4),Z4(10,4),Z5(10,4)
      DIMENSION ZF1(10,4),ZF2(10,4),ZF3(10,4),ZF4(10,4),ZF5(10,4)
      DIMENSION ZF6(10,4),ZF7(10,4),ZF8(10,4)
      DIMENSION FM1(10,4),FM2(10,4),FM3(10,4),FM4(10,4),FM5(10,4)
      DIMENSION FM6(10,4),FM7(10,4),FM8(10,4)
      DIMENSION FG(4),YC(10,4)
      REAL M1T,M2T,M3T,M4T,M5T,M6T,M7T,M8T,K(9,4)
      READ(5,1)BMH,SCL1
      READ(5,2)(RHO(I),I=1,4)
      READ(5,3)(MESH(I),I=1,10)
      READ(5,4)(LAPEPT(I),I=1,10)
      READ(5,5)(FACTOR(I),I=1,3)
      READ(5,6)(F1(I),I=1,10)
      READ(5,7)((FICHEM(I,J),I=1,10),J=1,3)
      READ(5,9)((P(I,J),I=1,9),J=1,4)
```

CONTINUED ......

```
      READ(5,9)((B(I,J),I=1,9),J=1,4)
      READ(5,8)(ELEM(I),I=1,4)
      READ(5,11)((Y(I,J),I=1,10),J=1,4)
      READ(5,11)((YC(I,J),I=1,10),J=1,4)
    1 FORMAT(F8.6,1X,F5.1)
    2 FORMAT(4F4.2)
    3 FORMAT(10I4)
    4 FORMAT(I3,9(1X,I3))
    5 FORMAT(3(1X,F4.2))
    6 FORMAT(10F5.2)
    7 FORMAT(10F5.2)
    8 FORMAT(4A7)
    9 FORMAT(9(1X,F6.4))
   11 FORMAT(10F7.4)
C
C     DEFINITION OF PARAMETERS TO BE CONSTANT
C     TRHOUGH THE ITERATIVE PROCESS
C
      FG(1)= 0.70
      FG(2)= 1.00
      FG(3)= 1.
      FG(4)= 1.00
C
      PCTS1= 77.
      RF= 34.
      VW1= (100.*SOL1/PCTS1 - SOL1)/60.
      VW5= 240./60.
      PCTS6= 100.00
      TON= 6.E5/SOL1
      UNIT= 1./TON
      MIT= 1.E4
      DO 10 I=1,4
      RHOU(I)= TON*RHO(I)
   10 CONTINUE
      DO 20 J=1,3
      A= 0.0
      DO 20 I=1,10
      F1MU(I,J)= F1(I)*F1CHEM(I,J)*FACTOR(J)
      F1MUC(I,J)= A + F1MU(I,J)
      A= F1MUC(I,J)
   20 CONTINUE
      A= 0.0
      DO 30 I=1,10
      F1MU(I,4)= 100.*F1(I) - (F1MU(I,1)+F1MU(I,2)+F1MU(I,3))
      F1MUC(I,4)= A + F1MU(I,4)
      A= F1MUC(I,4)
   30 CONTINUE
      DO 40 J=1,4
      DO 40 I=1,10
      F7MU(I,J)= 0.0
   40 CONTINUE
      VW7= 0.0
C
C     BEGINNING OF THE ITERATIVE PROCESS
C
      M= 1
   15 DO 50 J=1,4
C
```

CONTINUED ......

```
C
C
C      SUMP
C
C
       A= 0.0
       DO 50 I=1,10
       F2MU(I,J)= F1MU(I,J) + F7MU(I,J)
       F2MUC(I,J)= A + F2MU(I,J)
       A= F2MUC(I,J)
  50   CUNTINUE
       VW2= VW1 + VW7
       DO 52 I=1,10
       A= 0.0
       B1= 0.0
       DO 52 J=1,4
       F1U(I)= A + F1MUC(I,J)
       F2(I)= B1 + F2MUC(I,J)
       A= F1U(I)
       B1= F2(I)
  52   CONTINUE
       A= 0.0
       DO 55 I=1,4
       M2T= A + F2MUC(10,I)
       A= M2T
  55   CONTINUE
       PCTS2= 100.*UNIT*M2T/(UNIT*M2T + VW2)
       DO 57 I=1,10
       FF1(I)= 100.*(M1T - F1U(I))/M1T
       FF2(I)= 100.*(M2T - F2(I))/M2T
  57   CONTINUE
C
C
C      CYCLONE
C
C
       VW4= RF*VW2/100.
       DO 60 J=1,4
       A= 0.0
       B1= 0.0
       DO 60 I=1,10
       F4MU(I,J)= Y(I,J)*F2MU(I,J)/100.
       F3MU(I,J)= F2MU(I,J) - F4MU(I,J)
       F4MUC(I,J)= A + F4MU(I,J)
       F3MUC(I,J)= B1 + F3MU(I,J)
       A= F4MUC(I,J)
       B1= F3MUC(I,J)
  60   CONTINUE
       B1= 0.0
       C= 0.0
       DO 70 J=1,4
       V(J)= F4MUC(10,J)/RHOU(J)
       M3T= B1 + F3MUC(10,J)
       M4T= C + F4MUC(10,J)
       B1= M3T
       C= M4T
  70   CONTINUL
       SOL4= M4T*UNIT
```

CONTINUED ......

```
      WADD= VW5 - VW4
C
C
C     BALL MILL
C
C
      VT= V(1) + V(2) + V(3) + V(4)
      RHOT= UNIT*M4T/VT
      TIME= BMH/(VW4 + VT)
      DO 80 J=1,4
      DO 80 I=1,9
      F5MUC(I,J)= F4MUC(I,J)*EXP(-FG(J)*B(I,J)*TIME**P(I,J))
   80 CONTINUE
      DO 90 J=1,4
      F5MUC(10,J)= F4MUC(10,J)
      F5MU(1,J)= F5MUC(1,J)
   90 CONTINUE
      A= 0.0
      DO 95 J=1,4
      M5T= A + F5MUC(10,J)
      A= M5T
   95 CONTINUE
      DO 100 J=1,4
      DO 100 I=2,10
      L= I - 1
      F5MU(I,J)= F5MUC(I,J) - F5MUC(L,J)
  100 CONTINUE
C
C
C     FLOTATION STAGE
C
C
      DO 500 J= 1,4
      A= 0.0
      B1= 0.0
      DO 500 I=1,10
      F6MU(I,J)= YC(I,J)*F5MU(I,J)
      F7MU(I,J)= F5MU(I,J) - F6MU(I,J)
      F6MUC(I,J)= A + F6MU(I,J)
      F7MUC(I,J)= B1 + F7MU(I,J)
      A= F6MUC(I,J)
      B1= F7MUC(I,J)
  500 CONTINUE
      DO 510 J=1,4
      A= 0.0
      DO 510 I=1,10
      F8MU(I,J)= F3MU(I,J) + F6MU(I,J)
      F8MUC(I,J)= A + F8MU(I,J)
      A= F8MUC(I,J)
  510 CONTINUE
      A= 0.0
      B1= 0.0
      C= 0.0
      DO 520 J=1,4
      M6T= A + F6MUC(10,J)
      M7T= B1 + F7MUC(10,J)
      M8T= C + F8MUC(10,J)
      A= M6T
```

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CONTINUED ......

```
      B1= M7T
      C= M8T
 520  CONTINUE
      VW3= VW2 - VW4
      VW6= 0.00
      VW7= VW5
      VW8= VW3 + VW6
      DO 110 I=1,10
      C= 0.0
      D1= 0.0
      E= 0.0
      F= 0.0
      G= 0.0
      H= 0.0
      R1(I)= 0.0
      R2(I)= 0.0
      R3(I)= 0.0
      R4(I)= 0.0
      R5(I)= 0.0
      R6(I)= 0.0
      R7(I)= 0.0
      R8(I)= 0.0
      DO 110 J=1,4
      F3(I)= C + F3MUC(I,J)
      F4(I)= D1 + F4MUC(I,J)
      F5(I)= E + F5MUC(I,J)
      F6(I)= F + F6MUC(I,J)
      F7(I)= G + F7MUC(I,J)
      F8(I)= H + F8MUC(I,J)
      R1(I)= R1(I) + F1MU(I,J)
      R2(I)= R2(I) + F2MU(I,J)
      R3(I)= R3(I) + F3MU(I,J)
      R4(I)= R4(I) + F4MU(I,J)
      R5(I)= R5(I) + F5MU(I,J)
      R6(I)= R6(I) + F6MU(I,J)
      R7(I)= R7(I) + F7MU(I,J)
      R8(I)= R8(I) + F8MU(I,J)
      C= F3(I)
      D1= F4(I)
      E= F5(I)
      F= F6(I)
      G= F7(I)
      H= F8(I)
 110  CONTINUE
      DO 120 I=1,10
      FF1(I)= 100.*(M1T - F1U(I))/M1T
      FF2(I)= 100.*(M2T - F2(I))/M2T
      FF3(I)= 100.*(M3T - F3(I))/M3T
      FF4(I)= 100.*(M4T - F4(I))/M4T
      FF5(I)= 100.*(M5T - F5(I))/M5T
      FF6(I)= 100.*(M6T - F6(I))/M6T
      FF7(I)= 100.*(M7T - F7(I))/M7T
      FF8(I)= 100.*(M8T - F8(I))/M8T
 120  CONTINUE
      DO 130 J=1,4
      CLMIN(J)= 100.*F4MUC(10,J)/F1MUC(10,J)
 130  CONTINUE
      CLOV= 100.*M4T/M1T
```

CONTINUED ......

```
      PCTS3= 100.*UNIT*M3T/(UNIT*M3T + VW3)
      PCTS4= 100.*UNIT*M4T/(UNIT*M4T + VW4)
      PCTS5= PCTS4
      PCTS7= 100.*UNIT*M7T/(UNIT*M7T + VW7)
      PCTS8= 100.*UNIT*M8T/(UNIT*M8T + VW8)
      A= ABS(M1T - M8T)
C
C
C
C    CONVERGENCE TEST OF STEADY STATE MASS FLOW CONDITIONS
C
C
      IF((A.LE.10.).OR.(M.EQ.50))GO TO 140
      M= M+1
      GO TO 15
C
C
C     END OF ITERATIVE PROCESS
C
 140  DO 145 J=1,4
      S1= 0.0
      S2= 0.0
      S3= 0.0
      S4= 0.0
      S5= 0.0
      S6= 0.0
      S7= 0.0
      S8= 0.0
      DO 145 I=1,10
      Z1(I,J)= 100.*F1MU(I,J)/F1MUC(10,J)
      Z2(I,J)= 100.*F2MU(I,J)/F2MUC(10,J)
      Z3(I,J)= 100.*F3MU(I,J)/F3MUC(10,J)
      Z4(I,J)= 100.*F4MU(I,J)/F4MUC(10,J)
      Z5(I,J)= 100.*F5MU(I,J)/F5MUC(10,J)
      Z6(I,J)= 100.*F6MU(I,J)/F6MUC(10,J)
      Z7(I,J)= 100.*F7MU(I,J)/F7MUC(10,J)
      Z8(I,J)= 100.*F8MU(I,J)/F8MUC(10,J)
      ZF1(I,J)= S1 + Z1(I,J)
      ZF2(I,J)= S2 + Z2(I,J)
      ZF3(I,J)= S3 + Z3(I,J)
      ZF4(I,J)= S4 + Z4(I,J)
      ZF5(I,J)= S5 + Z5(I,J)
      ZF6(I,J)= S6 + Z6(I,J)
      ZF7(I,J)= S7 + Z7(I,J)
      ZF8(I,J)= S8 + Z8(I,J)
      FM1(I,J)= 100. - ZF1(I,J)
      FM2(I,J)= 100. - ZF2(I,J)
      FM3(I,J)= 100. - ZF3(I,J)
      FM4(I,J)= 100. - ZF4(I,J)
      FM5(I,J)= 100. - ZF5(I,J)
      FM6(I,J)= 100. - ZF6(I,J)
      FM7(I,J)= 100. - ZF7(I,J)
      FM8(I,J)= 100. - ZF8(I,J)
      S1= ZF1(I,J)
      S2= ZF2(I,J)
      S3= ZF3(I,J)
      S4= ZF4(I,J)
      S5= ZF5(I,J)
```

CONTINUED ......

```
      S6= ZF6(I,J)
      S7= ZF7(I,J)
      S8= ZF8(I,J)
 145  CONTINUE
      DO 199 J=1,4
      DO 199 I=1,10
      YC(I,J)= 100.*YC(I,J)
 199  CONTINUE
      WRITE(6,310)SOL1,BMH,(FG(I),I=1,4)
      DO 301 I=1,9
      WRITE(6,315)MESH(I),F1(I),(F1CHEM(I,J),J=1,3),(B(I,J),J=1,4),(P(I,
     @J),J=1,4)
 301  CONTINUE
 310  FORMAT('1'//' ',15X,'INPUT DATA USED IN SIMULATING A PB-ZN ORE GRI
     @NDING OPERATION'//' ',15X,'FLOW RATE INPUT (FRESH FEED):',F10.2,'
     @METRIC TONS PER HOUR'/' ',15X,'BALL MILL HOLDUP:',16X,F6.2,' CUBIC
     @ METERS'//' ',15X,'GRINDING SCALE FACTOR FOR PBS:',F10.2//' ',15X,
     @'GRINDING SCALE FACTOR FOR ZNS:',F10.2//' ',15X,
     @'GRINDING SCALE FACTOR FOR FES2:',F9.2//' ',15X,
     @'GRINDING SCALE FACTOR FOR CAL/DOL:',F6.2/////' ',15X,
     @'MESH',3X,'SIZE',3X,'CHEMICAL  ASSAYS',5X,'SPECIFIC RATE OF BREAKA
     @GE',7X,'P  ORDER OF BREAKAGE'/' ',16X,'NO',3X,'ASSAYS',4X,'PB',4X,
     @'ZN',4X,'FE',10X,'PBS',3X,'ZNS',2X,'FES2 CAL/DOL',4X,'PBS',4X,
     @'ZNS',2X,'FES2 CAL/DOL'//)
 315  FORMAT(' ',15X,I4,2X,F6.2,1X,3F6.2,3X,4F7.4,2X,4F7.4)
      WRITE(6,316)MESH(10),F1(10),(F1CHEM(10,J),J=1,3)
 316  FORMAT(' ',15X,I4,2X,F6.2,1X,3F6.2)
      WRITE(6,317)
      DO 302 I=1,10
      WRITE(6,318)MESH(I),(Y(I,J),J=1,4),(YC(I,J),J=1,4)
 302  CONTINUE
 317  FORMAT(///' ',15X,'MESH',4X,'CYCLONE SELEC INDEX, Y',5X,'FLOTATION
     @ RECOVEPY, YC'/' ',16X,'NO',6X,'PB',4X,'ZN',4X,'FE CAL/DOL',5X,'PB
     @',4X,'ZN',4X,'FE CAL/DOL'//)
 318  FORMAT(' ',15X,I4,3X,4F6.2,3X,4F6.2)
      WRITE(6,200)M,RHUT,TIME,CLOV,(CLMIN(J),J=1,4),PCTS1,PCTS2,PCTS3,
     @PCTS4,PCTS5,PCTS6,PCTS7,PCTS8
 200  FORMAT('1'///' ',22X,'ITERATION:',I3,18X,'SP. GR. BALL MILL FEED:'
     @,F5.2/' ',22X,'RESIDENCE TIME:',F5.2,' MIN',11X,'TOTAL CIRC. LOAD:
     @',F7.2//' ',31X,'PBS C.L.  ',F6.2,11X,'ZNS C.L. ',F6.2/' ',
     @31X,'FES2 C.L. ',F6.2,7X,'CAL/DOL C.L. ',F6.2//' ',31X,
     @'PCT SOLIDS BY WT, STREAM NO ONE:',F9.2/' ',31X,
     @'PCT SOLIDS BY WT, STREAM NO TWO:',F9.2/' ',31X,'PCT SOLIDS BY WT,
     @ STREAM NO THREE:',F7.2/' ',31X,'PCT SOLIDS BY WT, STREAM NO FOUR:
     @',F8.2/' ',31X,'PCT SOLIDS BY WT, STREAM NO FIVE:',F8.2/' ',31X,'P
     @CT SOLIDS BY WT, STREAM NO SIX:',F9.2/' ',31X,'PCT SOLIDS BY WT, S
     @TREAM NO SEVEN:',F7.2/' ',31X,'PCT SOLIDS BY,WT, STREAM NO EIGHT:'
     @,F7.2///' ',35X,'CUMULATIVE WT PCT FINER - OVERALL'///)
      WRITE(6,210)
 210  FORMAT(' ',14X,'MESH',4X,'SIZE'/' ',15X,'NO',5X,'MICR',3X,
     @'STREAM 1',1X,'STREAM 2',1X,'STREAM 3',1X,'STREAM 4',1X,'STREAM 5'
     @,1X,'STREAM 6',1X,'STREAM 7',1X,'STREAM 8'/)
      DO 220 I=1,9
      WRITE(6,250)MESH(I),LAPERT(I),FF1(I),FF2(I),FF3(I),FF4(I),FF5(I),
     @FF6(I),FF7(I),FF8(I)
 250  FORMAT(' ',14X,I4,5X,I3,8(3X,F6.2)//)
 220  CONTINUE
      J1= 1
```

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CONTINUED ......

```
      J2= 2
      J3= 3
      J4= 4
      J5= 5
      J6= 6
      J7= 7
      J8= 8
      WRITE(6,255)J1
      DO 146 I=1,10
      WRITE(6,260)MESH(I),LAPERT(I),R1(I),(F1MU(I,J),J=1,4)
 146  CONTINUE
      WRITE(6,255)J2
      DO 150 I=1,10
      WRITE(6,260)MESH(I),LAPERT(I),R2(I),(F2MU(I,J),J=1,4)
 150  CONTINUE
      WRITE(6,255)J3
      DO 160 I=1,10
      WRITE(6,260)MESH(I),LAPERT(I),R3(I),(F3MU(I,J),J=1,4)
 160  CONTINUE
      WRITE(6,255)J4
      DO 170 I=1,10
      WRITE(6,260)MESH(I),LAPERT(I),R4(I),(F4MU(I,J),J=1,4)
 170  CONTINUE
      WRITE(6,255)J5
      DO 180 I=1,10
      WRITE(6,260)MESH(I),LAPERT(I),R5(I),(F5MU(I,J),J=1,4)
 180  CONTINUE
      WRITE(6,255)J6
      DO 600 I=1,10
      WRITE(6,260)MESH(I),LAPERT(I),R6(I),(F6MU(I,J),J=1,4)
 600  CONTINUE
      WRITE(6,255)J7
      DO 610 I=1,10
      WRITE(6,260)MESH(I),LAPERT(I),R7(I),(F7MU(I,J),J=1,4)
 610  CONTINUE
      WRITE(6,255)J8
      DO 620 I=1,10
      WRITE(6,260)MESH(I),LAPERT(I),R8(I),(F8MU(I,J),J=1,4)
 620  CONTINUE
 255  FORMAT('1'////,22X,'MINERAL UNITS RETAINED',10X,'STREAM NO: ',
     @I2//' ',22X,'MESH',4X,'SIZE'/' ',23X,'NO',5X,'MICR',5X,'OVERALL',
     @5X,'PBS',6X,'ZNS',5X,'FES2',3X,'CAL/DOL'/)
 260  FORMAT(' ',22X,I4,5X,I3,3X,5F9.2//)
      WRITE(6,265)J1
      DO 181 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z1(I,J),J=1,4)
 181  CONTINUE
      WRITE(6,265)J2
      DO 182 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z2(I,J),J=1,4)
 182  CONTINUE
      WRITF(6,265)J3
      DO 183 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z3(I,J),J=1,4)
 183  CONTINUE
      WRITE(6,265)J4
      DO 184 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z4(I,J),J=1,4)
```

CONTINUED ......

```
 184  CONTINUE
      WRITE(6,265)J5
      DO 185 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z5(I,J),J=1,4)
 185  CONTINUE
      WRITE(6,265)J6
      DO 630 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z6(I,J),J=1,4)
 630  CONTINUE
      WRITE(6,265)J7
      DO 640 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z7(I,J),J=1,4)
 640  CONTINUE
      WRITE(6,265)J8
      DO 650 I=1,10
      WRITE(6,270)MESH(I),LAPERT(I),(Z8(I,J),J=1,4)
 650  CONTINUE
 265  FORMAT('1'////' ',22X,'MINERAL DISTRIBUTION, PCT',7X,'STREAM NO: '
     @,I2//' ',22X,'MESH',4X,'SIZE'/' ',23X,'NO',5X,'MICR',5X,'PBS',
     @6X,'ZNS',4X,'FES2',4X,'CAL/DOL'/)
 270  FORMAT(' ',22X,I4,5X,I3,5(3X,F6.2)//)
      WRITE(6,275)J1
      DO 191 I=1,9
      WRITE(6,280)MESH(I),LAPERT(I),(FM1(I,J),J=1,4)
 191  CONTINUE
      WRITE(6,275)J2
      DO 192 I=1,9
      WRITE(6,280)MESH(I),LAPERT(I),(FM2(I,J),J=1,4)
 192  CONTINUE
      WRITE(6,275)J3
      DO 193 I=1,9
      WRITE(6,280)MESH(I),LAPERT(I),(FM3(I,J),J=1,4)
 193  CONTINUE
      WRITE(6,275)J4
      DO 194 I=1,9
      WRITE(6,280)MESH(I),LAPERT(I),(FM4(I,J),J=1,4)
 194  CONTINUE
      WRITE(6,275)J5
      DO 195 I=1,9
      WRITE(6,280)MESH(I),LAPERT(I),(FM5(I,J),J=1,4)
 195  CONTINUE
      WRITE(6,275)J6
      DO 660 I=1,10
      WRITE(6,280)MESH(I),LAPERT(I),(FM6(I,J),J=1,4)
 660  CONTINUE
      WRITE(6,275)J7
      DO 670 I=1,10
      WRITE(6,280)MESH(I),LAPERT(I),(FM7(I,J),J=1,4)
 670  CONTINUE
      WRITE(6,275)J8
      DO 680 I=1,10
      WRITE(6,280)MESH(I),LAPERT(I),(FM8(I,J),J=1,4)
 680  CONTINUE
 275  FORMAT('1'////' ',22X,'CUM MINERAL PCT FINER',3X,'STREAM NO: ',
     @I2//' ',22X,'MESH',4X,'SIZE',/' ',23X,'NO',5X,'MICR',5X,'PBS',
     @6X,'ZNS',4X,'FES2',4X,'CAL/DOL'/)
 280  FORMAT(' ',22X,I4,5X,I3,5(3X,F6.2)//)
C
```

CONTINUED ......

```
C
C       CALCULATING THE INSTANTANEOUS RATE-OF-BREAKAGE
C
C
        DO 147 J=1,4
        DO 147 I=1,9
        K(I,J)= B(I,J)*TIME**(P(I,J) - 1.)*FG(J)
  147   CONTINUE
        WRITE(6,303)
        DO 196 I=1,9
        WRITE(6,304)MESH(I),LAPERT(I),(K(I,J),J=1,4)
  196   CONTINUE
  303   FORMAT('1'////' ',15X,'INSTANTANEOUS RATES OF BREAKAGE AT THE TIME
       @'/' ',57X,'-1'/' ',15X,'STEADY STATE CONDITIONS WERE REACHED, MIN'
       @//' ',15X,'MESH',4X,'SIZE'/' ',16X,'NO',5X,'MICR',5X,'PBS',6X,'ZNS
       @',5X,'FES2',4X,'CAL/DOL'/)
  304   FORMAT(' ',15X,I4,5X,I3,4(4X,F5.3)//)
        STOP
        END
$DATA
C
C ... DATA CARDS
C
$
```

INPUT DATA USED IN SIMULATING A PB-ZN ORE GRINDING OPERATION

FLOW RATE INPUT (FRESH FEED): 154.20 METRIC TONS PER HOUR
BALL MILL HOLDUP: 8.37 CUBIC METERS

GRINDING SCALE FACTOR FOR PBS: 0.70

GRINDING SCALE FACTOR FOR ZNS: 1.00

GRINDING SCALE FACTOR FOR FES2: 1.00

GRINDING SCALE FACTOR FOR CAL/DOL: 1.00

MESH NO	SIZE ASSAYS	CHEMICAL ASSAYS PB	ZN	FE	SPECIFIC RATE OF BREAKAGE PBS	ZNS	FES2	CAL/DOL	P ORDER OF BREAKAGE PBS	ZNS	FES2	CAL/DOL
28	19.42	1.48	4.99	10.23	0.9141	0.7581	0.6797	0.6840	0.7483	0.8145	0.6452	0.8773
35	7.96	1.25	6.01	6.95	0.8155	0.6548	0.4826	0.5842	0.7852	0.9210	0.8653	0.9973
48	7.39	2.17	7.49	8.35	0.5981	0.4711	0.3380	0.3730	0.9831	1.0460	0.9808	1.1673
65	5.72	1.40	5.19	5.97	0.3948	0.3164	0.2430	0.2779	1.1088	1.0765	0.9803	1.1622
100	7.62	2.94	8.45	6.76	0.2708	0.1808	0.1329	0.1725	1.0421	1.0457	0.9213	1.1588
150	9.05	1.55	5.22	4.46	0.1615	0.0990	0.0601	0.1631	1.0365	1.0890	1.2340	0.9272
200	8.16	1.37	4.94	4.01	0.1085	0.0737	0.0476	0.0934	0.9679	0.9770	1.0694	1.0294
270	8.66	1.59	5.54	4.40	0.0813	0.0408	0.0314	0.0573	0.7736	1.0535	1.0053	1.0865
400	5.38	1.64	5.62	4.45	0.0595	0.0318	0.0239	0.0444	0.7825	1.0498	1.0511	1.0577
-400	20.66	1.59	6.00	5.88								

MESH NO	CYCLONE SELEC INDEX, Y PB	ZN	FE	CAL/DOL	FLOTATION RECOVERY, YC PB	ZN	FE	CAL/DOL
28	98.86	98.90	98.99	97.27	0.00	0.00	0.00	0.00
35	94.57	98.63	91.06	96.81	4.51	0.12	0.01	0.03
48	100.00	100.00	98.80	88.38	19.07	1.38	0.17	0.16
65	100.00	98.82	95.95	76.15	53.48	1.46	0.12	0.34
100	98.00	96.62	91.27	54.13	60.66	2.96	0.07	0.03
150	97.91	81.53	95.02	36.60	60.67	6.19	0.13	0.00
200	98.28	66.91	85.05	35.17	60.58	11.23	0.46	0.28
270	93.70	45.56	68.96	23.06	63.50	14.18	0.72	1.53
400	78.45	41.19	48.97	28.26	63.49	13.36	1.90	0.33
-400	39.51	28.86	35.45	29.09	49.53	9.21	3.22	0.42

ITERATION: 22
RESIDENCE TIME: 3.08 MIN

SP. GR. BALL MILL FEED: 3.53
TOTAL CIRC. LOAD: 150.19

PBS C.L. 139.41
FES2 C.L. 386.61

ZNS C.L. 205.39
CAL/DOL C.L. 99.61

PCT SOLIDS BY WT. STREAM NO ONE: 77.00
PCT SOLIDS BY WT. STREAM NO TWO: 57.07
PCT SOLIDS BY WT. STREAM NO THREE: 44.06
PCT SOLIDS BY WT. STREAM NO FOUR: 70.42
PCT SOLIDS BY WT. STREAM NO FIVE: 70.42
PCT SOLIDS BY WT. STREAM NO SIX: 100.00
PCT SOLIDS BY WT. STREAM NO SEVEN: 48.52
PCT SOLIDS BY WT. STREAM NO EIGHT: 44.94

CUMULATIVE WT PCT FINER - OVERALL

MESH NO	SIZE MICR	STREAM 1	STREAM 2	STREAM 3	STREAM 4	STREAM 5			
28	592	80.58	90.44	99.47	84.64	97.22	100.00	97.16	99.49
35	419	72.62	86.35	99.04	78.21	95.82	99.92	95.72	99.07
48	296	65.23	80.94	97.93	70.03	91.83	99.00	91.66	97.97
65	209	59.51	74.56	95.15	61.34	85.08	95.70	84.83	95.17
100	148	51.89	61.68	86.13	45.98	68.77	86.08	68.36	86.13
150	105	42.84	48.38	74.34	31.70	52.58	70.71	52.15	74.21
200	74	34.68	35.62	60.04	19.95	36.63	52.62	36.25	59.78
270	53	26.02	25.28	44.47	12.95	24.92	31.95	24.75	44.03
400	37	20.04	20.03	35.63	10.01	19.69	23.50	19.60	35.21

MINERAL DISTRIBUTION, PCT   STREAM NO: 1

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	17.34	16.60	30.19	17.77
35	419	6.00	8.19	8.41	7.90
48	296	9.67	9.48	9.38	6.71
65	209	4.83	5.08	5.19	5.91
100	148	13.51	11.03	7.83	7.04
150	105	8.46	8.09	6.13	9.72
200	74	6.74	6.90	4.97	8.94
270	53	8.31	8.22	5.79	9.26
400	37	5.32	5.18	3.64	5.73
-400	-37	19.81	21.23	18.46	21.02

MINERAL DISTRIBUTION, PCT   STREAM NO: 2

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	13.64	6.73	8.25	10.55
35	419	5.15	3.41	2.69	4.80
48	296	8.25	4.90	4.37	5.91
65	209	5.09	5.49	5.31	7.05
100	148	12.95	16.64	15.41	11.09
150	105	10.72	17.99	18.02	10.42
200	74	9.17	12.14	15.96	11.46
270	53	9.73	9.99	12.26	9.55
400	37	5.52	4.80	3.64	6.05
-400	-37	19.78	17.90	14.09	23.10

MINERAL DISTRIBUTION, PCT   STREAM NO: 3

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	1.05	0.25	0.42	0.58
35	419	1.89	0.16	1.21	0.31
48	296	0.00	0.00	0.26	1.37
65	209	0.00	0.22	1.08	3.36
100	148	1.75	1.93	6.73	10.17
150	105	1.51	11.43	4.49	13.22
200	74	1.06	13.81	11.95	14.86
270	53	4.13	18.70	19.04	14.70
400	37	8.01	9.70	9.29	8.68
-400	-37	80.61	43.78	45.53	32.76

MINERAL DISTRIBUTION, PCT   STREAM NO: 4

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	15.84	9.38	10.21	20.53
35	419	5.72	4.74	3.07	9.30
48	296	9.68	6.91	5.39	10.46
65	209	5.98	7.66	6.36	10.74
100	148	14.91	22.67	17.58	12.01
150	105	12.33	20.69	21.39	7.63
200	74	10.58	11.46	16.97	8.06
270	53	10.70	6.42	10.86	4.41
400	37	5.09	2.79	2.23	3.42
-400	-37	9.18	7.28	6.24	13.44

MINERAL DISTRIBUTION, PCT STREAM NO: 5

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	3.58	1.41	2.50	3.27
35	419	1.83	0.82	1.19	1.68
48	296	3.39	2.33	3.04	5.10
65	209	5.40	5.35	5.30	8.20
100	148	14.04	18.66	17.26	15.13
150	105	16.58	22.86	21.00	11.09
200	74	15.04	15.50	18.60	14.00
270	53	14.97	11.76	13.55	9.96
400	37	7.30	4.90	3.68	6.37
-400	-37	17.86	16.41	13.28	25.20

MINERAL DISTRIBUTION, PCT STREAM NO: 6

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	0.00	0.00	0.00	0.00
35	419	0.15	0.01	0.02	0.14
48	296	1.19	0.42	0.70	2.27
65	209	5.32	1.02	0.86	7.75
100	148	15.69	7.22	1.64	1.26
150	105	18.53	18.49	3.71	0.00
200	74	16.78	22.75	11.76	10.90
270	53	17.51	21.79	13.66	42.40
400	37	8.54	8.56	9.51	5.84
-400	-37	16.29	19.75	58.14	29.44

MINERAL DISTRIBUTION, PCT STREAM NO: 7

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	7.84	1.53	2.52	3.28
35	419	3.82	0.89	1.20	1.69
48	296	6.01	2.49	3.05	5.11
65	209	5.50	5.71	5.33	8.20
100	148	12.08	19.60	17.37	15.18
150	105	14.27	23.22	21.13	11.13
200	74	12.97	14.90	18.65	14.01
270	53	11.96	10.93	13.55	9.85
400	37	5.83	4.60	3.64	6.37
-400	-37	19.72	16.14	12.55	25.19

MINERAL DISTRIBUTION, PCT STREAM NO: 8

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	0.25	0.21	0.41	0.57
35	419	0.57	0.14	1.17	0.31
48	296	0.90	0.07	0.27	1.38
65	209	4.03	0.35	1.07	3.38
100	146	12.30	2.76	6.59	10.14
150	105	14.39	12.54	4.47	13.17
200	74	12.96	15.22	11.94	14.85
270	53	14.26	19.19	18.69	14.79
400	37	8.41	9.52	9.30	8.67
-400	-37	31.92	40.00	45.69	32.74

CUM MINERAL PCT FINER   STREAM NO: 1

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	82.66	83.40	69.81	82.23
35	419	76.66	75.21	61.40	74.33
48	296	66.99	65.73	52.02	67.62
65	209	62.16	60.65	46.83	61.[illegible]
100	148	48.65	49.62	39.00	54.[illegible]
150	105	40.18	41.53	32.87	44.95
200	74	33.44	34.62	27.89	36.01
270	53	25.14	26.41	22.10	26.75
400	37	19.81	21.23	18.46	21.02

CUM MINERAL PCT FINER   STREAM NO: 2

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	86.36	93.27	91.75	89.45
35	419	81.21	89.86	89.05	84.64
48	296	72.96	84.96	84.69	78.73
65	209	67.87	79.46	79.38	71.68
100	148	54.92	62.82	63.97	60.59
150	105	44.19	44.83	45.95	50.16
200	74	35.03	32.69	29.99	38.70
270	53	25.30	22.70	17.73	29.15
400	37	19.78	17.90	14.09	23.10

CUM MINERAL PCT FINER   STREAM NO: 3

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	98.95	99.75	99.88	99.42
35	419	97.07	99.58	98.38	99.12
48	296	97.07	99.58	98.11	97.74
65	209	97.07	99.36	97.04	94.38
100	148	95.32	97.43	90.30	84.21
150	105	93.81	86.00	85.81	70.99
200	74	92.75	72.19	73.87	56.13
270	53	88.62	53.48	54.82	41.43
400	37	80.61	43.78	45.53	32.76

CUM MINERAL PCT FINER   STREAM NO: 4

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	84.16	90.62	89.79	79.47
35	419	78.44	85.87	86.72	70.16
48	296	68.76	78.96	81.33	59.71
65	209	62.78	71.30	74.97	48.97
100	148	47.87	48.63	57.39	36.96
150	105	35.55	27.95	36.00	29.33
200	74	24.97	16.49	19.03	21.26
270	53	14.26	10.07	8.47	16.86
400	37	9.18	7.28	6.24	13.44

CUM MINERAL PCT FINER STREAM NO: 5

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	96.42	98.59	97.80	96.73
35	419	94.59	97.77	96.30	95.05
48	296	91.19	95.44	93.27	89.94
65	209	85.79	90.09	87.57	81.75
100	148	71.75	71.43	70.71	66.62
150	105	55.17	48.58	49.71	55.53
200	74	40.13	33.07	30.91	41.53
270	53	25.16	21.32	16.96	31.57
400	37	17.86	16.41	13.28	25.20

CUM MINERAL PCT FINER STREAM NO: 6

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	100.00	100.00	100.00	100.00
35	419	99.85	99.99	99.98	99.86
48	296	98.66	99.57	99.28	97.59
65	209	93.33	98.55	98.42	89.84
100	148	77.65	91.33	96.78	88.58
150	105	59.12	72.84	93.06	88.58
200	74	42.34	50.10	81.31	77.68
270	53	24.83	28.31	67.65	35.28
400	37	16.29	19.75	58.14	29.44

CUM MINERAL PCT FINER STREAM NO: 7

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	92.16	98.47	97.48	96.72
35	419	88.33	97.59	96.28	95.03
48	296	82.33	95.10	93.22	89.92
65	209	76.83	89.39	87.69	81.72
100	148	64.75	69.78	70.62	66.54
150	105	50.48	46.57	49.39	55.41
200	74	37.51	31.66	30.54	41.40
270	53	25.56	20.74	16.59	31.55
400	37	19.72	16.14	12.95	25.19

CUM MINERAL PCT FINER STREAM NO: 8

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	99.75	99.79	99.59	99.43
35	419	99.17	99.65	98.42	99.12
48	296	98.27	99.58	98.15	97.74
65	209	94.24	99.23	97.08	94.36
100	148	81.94	96.47	90.49	84.22
150	105	67.55	83.93	86.02	71.05
200	74	54.59	68.71	74.08	56.20
270	53	40.33	49.52	55.19	41.41
400	37	31.92	40.00	45.89	32.74

INSTANTANEOUS RATES OF BREAKAGE AT THE TIME STEADY STATE CONDITIONS WERE REACHED, MIN^{-1}

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/COL
28	592	0.482	0.615	0.456	0.596
35	419	0.448	0.599	0.415	0.582
48	296	0.411	0.496	0.331	0.450
65	209	0.312	0.345	0.238	0.334
100	148	0.199	0.190	0.122	0.206
150	105	0.118	0.109	0.078	0.150
200	74	0.073	0.072	0.051	0.097
270	53	0.044	0.043	0.032	0.063
400	37	0.033	0.034	0.025	0.047

V.3.2 Results at 190.3 mtph

INPUT DATA USED IN SIMULATING A FE-ZN ORE GRINDING OPERATION

FLOW RATE INPUT (FRESH FEED): 190.38 METRIC TONS PER HOUR
BALL MILL HOLDUP: 8.37 CUBIC METERS

GRINDING SCALE FACTOR FOR PBS: 0.70

GRINDING SCALE FACTOR FOR ZNS: 1.00

GRINDING SCALE FACTOR FOR FES2: 1.00

GRINDING SCALE FACTOR FOR CAL/DOL: 1.00

MESH NO	SIZE ASSAYS	CHEMICAL ASSAYS PB	ZN	FE	SPECIFIC RATE OF BREAKAGE PBS	ZNS	FES2	CAL/DOL	P ORDER OF BREAKAGE PBS	ZNS	FES2	CAL/DOL
28	24.24	1.44	4.68	4.71	0.5141	0.7581	0.6797	0.6840	0.7483	0.8145	0.6452	0.8772
35	5.94	2.32	5.82	3.71	0.8155	0.6548	0.4826	0.5842	0.7852	0.9210	0.6653	0.9973
48	6.31	2.75	6.11	3.83	0.5981	0.4711	0.3380	0.3735	0.9631	1.1460	0.9806	1.1673
65	6.10	0.43	3.77	2.04	0.3948	0.3164	0.2430	0.2779	1.1088	1.0765	0.9803	1.1622
100	10.20	1.58	3.63	1.84	0.2708	0.1808	0.1329	0.1725	1.0421	1.0457	0.9213	1.1588
150	10.33	1.62	3.61	1.93	0.1615	0.0990	0.0601	0.1631	1.0365	1.0890	1.2340	0.9272
200	8.12	1.28	3.49	1.66	0.1285	0.0737	0.0476	0.1534	1.9679	0.9770	1.0654	[illegible]
270	7.47	1.25	4.05	1.73	0.0813	0.0418	0.0314	0.0573	0.7736	1.0535	[illegible]	[illegible]
400	3.89	1.31	3.99	[illegible]	0.0595	0.0318	0.0239	0.0444	0.7825	1.0456	1.4511	1.0577
-400	17.41	1.70	4.60	2.84								

MESH NO	CYCLONE SELEC INDEX, Y PB	ZN	FE	CAL/DOL	FLOTATION RECOVERY, YC PB	ZN	FE	CAL/DOL
28	100.0	100.0	98.64	57.10	0.00	0.01	0.01	0.06
35	99.70	99.67	97.76	98.[illegible]1	4.51	0.12	0.01	[illegible]
48	98.63	98.[illegible]3	99.04	89.70	19.17	1.38	0.17	[illegible]
65	99.87	96.54	98.93	67.5[illegible]	53.48	1.46	0.12	0.34
100	99.63	94.66	98.45	47.[illegible]	60.68	2.56	0.17	0.03
150	98.31	88.78	95.79	32.69	60.67	6.15	0.13	[illegible]
200	98.64	79.61	91.79	28.21	61.58	11.23	[illegible].46	0.26
270	96.[illegible]4	61.63	81.65	28.19	63.50	14.18	[illegible].72	1.5[illegible]
400	83.57	41.76	76.46	19.2[illegible]	63.49	13.36	1.90	0.33
-400	62.41	46.63	69.51	41.41	49.53	9.21	3.22	0.42

ITERATION: 33
RESIDENCE TIME: 1.83 MIN

SP. GR. BALL MILL FEED: 3.37
TOTAL CIRC. LOAD: 161.71

PRS C.L. 173.01
FFS2 C.L. 801.79

ZNS C.L. 319.61
CAL/DCL C.L. 125.06

PCT SOLIDS BY WT. STREAM NO ONE: 78.80
PCT SOLIDS BY WT. STREAM NO TWO: 56.76
PCT SOLIDS BY WT. STREAM NO THREE: 47.94
PCT SOLIDS BY WT. STREAM NO FOUR: 66.74
PCT SOLIDS BY WT. STREAM NO FIVE: 66.74
PCT SOLIDS BY WT. STREAM NO SIX: 100.00
PCT SOLIDS BY WT. STREAM NO SEVEN: 51.43
PCT SOLIDS BY WT. STREAM NO EIGHT: 48.37

CUMULATIVE WT PCT FINER - OVERALL

MESH NO	SIZE MICR	STREAM 1	STREAM 2	STREAM 3	STREAM 4	STREAM 5	STREAM 6	STREAM 7	STREAM 8
28	592	75.76	87.35	99.05	81.12	93.98	100.00	93.86	99.13
35	417	69.82	83.38	98.88	75.17	91.18	99.79	91.00	98.91
48	296	63.51	75.55	97.06	64.62	83.29	97.56	83.00	97.02
65	209	57.41	68.04	91.22	55.76	74.39	92.33	74.02	91.26
100	149	47.21	53.62	76.50	41.50	57.73	81.68	57.24	76.69
150	105	36.88	41.85	63.67	26.76	43.49	63.64	43.08	63.67
200	74	28.76	31.35	48.21	20.90	31.60	48.64	31.25	48.23
270	53	21.29	21.97	34.82	15.16	22.53	31.83	22.34	34.71
400	37	17.46	16.38	28.12	13.23	19.05	25.23	18.93	28.01

MINERAL DISTRIBUTION, PCT STREAM NO: 1

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	21.92	25.69	36.68	23.10
35	419	8.65	7.83	7.47	5.62
48	296	10.89	6.73	8.19	5.68
65	209	1.65	5.21	4.22	5.40
100	148	10.12	8.39	6.36	10.63
150	105	11.51	8.45	6.75	10.74
200	74	6.53	6.42	4.57	3.55
270	53	5.86	6.85	4.36	7.78
400	37	4.42	3.52	2.64	4.00
-400	-37	19.46	18.93	16.75	17.30

MINERAL DISTRIBUTION, PCT STREAM NO: 2

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	18.26	9.97	6.75	14.78
35	419	8.33	3.28	2.38	4.46
48	296	11.58	5.53	3.92	8.60
65	209	3.96	7.74	4.91	8.54
100	148	10.24	17.90	15.20	13.79
150	105	11.34	21.31	22.79	8.66
200	74	7.59	9.51	13.35	9.84
270	53	5.97	7.08	10.66	7.83
400	37	4.13	2.85	4.12	3.51
-400	-37	18.78	14.93	15.88	19.59

MINERAL DISTRIBUTION, PCT STREAM NO: 3

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	0.03	0.00	0.90	0.97
35	419	0.29	0.05	0.82	0.20
48	296	1.57	0.58	0.37	2.[illegible]
65	209	0.06	1.57	0.81	0.55
100	148	0.43	4.83	2.29	16.24
150	105	1.43	12.07	9.32	13.15
200	74	1.23	14.11	10.64	15.93
270	53	5.50	15.24	19.[illegible]	12.66
400	37	7.84	8.37	9.43	6.40
-400	-37	81.65	40.20	47.03	25.89

MINERAL DISTRIBUTION, PCT STREAM NO: 4

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DOL
28	592	19.99	11.31	7.46	25.78
35	419	9.09	4.07	2.59	7.64
48	296	12.53	6.76	4.32	13.86
65	209	4.33	9.51	5.42	10.85
100	148	10.95	21.13	16.65	11.85
150	103	12.28	23.60	24.34	5.09
200	74	8.19	8.38	13.66	4.98
270	53	6.02	5.07	9.71	3.98
400	37	3.78	1.48	3.51	1.21
-400	-37	12.83	8.68	12.31	14.57

MINERAL DISTRIBUTION, PCT   STREAM NO: 5

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DCL
28	592	7.32	3.26	2.74	8.08
35	419	4.31	1.64	1.72	3.51
48	296	7.89	4.23	3.35	10.77
65	209	7.26	9.14	4.56	10.98
100	148	[illegible]	[illegible]	16.17	16.29
150	105	16.12	28.52	24.66	6.57
200	74	11.51	11.10	14.42	10.86
270	53	8.63	6.96	[illegible]	7.96
400	37	5.38	2.83	4.36	3.12
-400	-37	15.46	13.99	16.17	21.45

MINERAL DISTRIBUTION, PCT   STREAM NO: 6

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DCL
28	592	0.00	0.00	0.00	0.00
35	419	0.46	0.03	0.02	0.34
48	296	3.11	0.89	0.71	5.50
65	209	8.06	1.82	0.74	11.52
100	148	16.43	9.19	1.40	1.56
150	105	21.24	24.14	3.57	[illegible]
200	74	14.43	15.06	8.22	9.71
270	53	11.34	19.41	10.21	38.51
400	37	[illegible]	5.78	10.26	3.29
-400	-37	18.92	19.69	64.47	28.77

MINERAL DISTRIBUTION, PCT   STREAM NO: 7

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DCL
28	592	14.18	3.51	2.76	8.11
35	419	7.97	1.75	1.74	3.52
48	295	12.35	4.46	3.37	10.78
65	209	6.56	8.58	4.59	10.98
100	148	9.96	21.09	16.29	16.33
150	105	12.27	25.62	24.83	7.00
200	74	6.78	10.55	14.47	10.87
270	53	6.13	8.22	11.46	7.87
400	37	3.85	2.63	4.31	3.12
-400	-37	18.03	13.59	16.77	21.43

MINERAL DISTRIBUTION, PCT   STREAM NO: 9

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DCL
28	592	0.00	0.00	0.84	0.96
35	419	0.38	0.05	0.49	0.20
48	295	2.66	0.62	0.39	2.01
65	209	6.75	0.83	[illegible]	6.57
100	148	13.81	5.75	2.23	16.18
150	105	17.16	[illegible]	8.97	[illegible]
200	74	12.27	15.15	10.48	[illegible]
270	53	[illegible]	19.27	18.42	12.78
400	37	7.19	7.83	9.46	6.39
-400	-37	29.19	[illegible]	48.13	[illegible]

CUM MINERAL PCT FINER   STREAM NO: 1

MESH NO	SIZE MICR	FES	ZNS	FES2	CAL/DOL
28	592	78.08	74.31	61.32	76.96
35	419	69.43	66.48	53.85	71.28
48	296	58.54	57.75	45.66	65.39
65	209	56.85	52.54	41.45	58.99
100	148	46.77	44.16	35.09	48.36
150	105	36.27	35.71	28.33	37.63
200	74	29.74	29.29	23.77	29.08
270	53	23.88	22.44	19.39	21.30
400	37	19.46	18.93	16.75	17.30

CUM MINERAL PCT FINER   STREAM NO: 2

MESH NO	SIZE MICR	FES	ZNS	FES2	CAL/DOL
28	592	81.74	90.93	93.22	85.22
35	419	73.41	87.65	90.84	80.76
48	296	61.83	82.12	86.92	72.16
65	209	57.86	74.39	82.01	63.22
100	148	47.82	56.48	66.81	49.43
150	105	36.48	35.17	44.02	40.77
200	74	28.89	25.66	30.67	30.92
270	53	22.91	17.78	20.71	23.10
400	37	18.78	14.93	15.88	19.59

CUM MINERAL PCT FINER   STREAM NO: 3

MESH NO	SIZE MICR	FES	ZNS	FES2	CAL/DOL
28	592	100.00	100.00	99.10	99.03
35	419	99.71	99.95	98.59	98.83
48	296	98.14	99.40	98.22	96.83
65	209	98.08	98.83	97.71	90.29
100	148	97.65	93.99	95.42	74.05
150	105	96.22	81.42	86.10	60.50
200	74	95.00	67.81	75.46	44.57
270	53	89.50	46.57	56.46	32.29
400	37	81.05	40.20	47.03	25.89

CUM MINERAL PCT FINER   STREAM NO: 4

MESH NO	SIZE MICR	FES	ZNS	FES2	CAL/DOL
28	592	80.01	88.69	92.54	74.22
35	419	70.92	84.61	89.98	66.37
48	296	58.39	77.85	85.62	52.51
65	209	54.05	66.35	80.21	41.67
100	148	43.10	47.22	63.52	29.82
150	105	30.82	23.62	39.18	24.73
200	74	22.63	15.24	25.53	19.75
270	53	16.61	10.17	15.82	15.78
400	37	12.83	6.08	12.31	14.57

CUM MINERAL PCT FINER STREAM NO: 5

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DCL
28	592	92.66	96.72	97.26	91.92
35	419	88.36	95.78	95.54	88.41
48	296	80.47	90.85	92.19	77.64
65	209	73.19	82.71	87.23	66.66
100	148	60.10	62.40	71.26	53.37
150	105	43.58	36.89	46.40	43.40
200	74	32.47	25.73	31.98	32.84
270	53	23.84	16.82	20.53	24.57
400	37	18.46	13.99	16.17	21.45

CUM MINERAL PCT FINER STREAM NO: 6

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DCL
28	592	100.00	100.00	100.00	100.00
35	419	99.60	99.57	99.98	99.66
48	296	96.48	99.78	99.27	94.16
65	209	88.43	97.26	98.84	82.24
100	148	71.99	88.08	97.13	80.68
150	105	51.75	63.93	93.16	80.68
200	74	37.32	44.88	84.95	73.97
270	53	25.98	25.47	74.78	32.06
400	37	18.92	19.69	64.47	28.77
-400	-37	0.00	0.00	0.00	0.00

CUM MINERAL PCT FINER STREAM NO: 7

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DCL
28	592	85.82	96.49	97.24	91.89
35	419	77.88	94.74	96.50	88.37
48	296	65.50	90.28	92.13	77.59
65	209	56.94	81.69	87.14	66.61
100	148	48.98	60.61	77.88	50.28
150	105	36.71	34.99	46.02	43.28
200	74	27.93	24.44	31.88	32.42
270	53	21.83	16.21	20.09	24.58
400	37	16.03	13.59	15.77	21.43
-400	-37	0.00	0.00	-0.00	-0.00

CUM MINERAL PCT FINER STREAM NO: 8

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DCL
28	592	100.00	100.00	99.16	99.64
35	419	99.62	99.95	98.68	98.64
48	296	96.76	99.33	96.29	96.82
65	209	90.01	98.50	97.77	90.26
100	148	76.15	92.75	95.53	74.08
150	105	59.04	78.16	86.57	60.98
200	74	46.77	63.01	76.08	45.08
270	53	36.39	43.73	57.66	32.29
400	37	29.19	35.95	48.16	25.96
-400	-37	0.00	-0.00	-0.00	-0.00

INSTANTANEOUS RATES OF BREAKAGE AT THE TIME STEADY STATE CONDITIONS WERE REACHED, MIN^{-1}

MESH NO	SIZE MICR	PBS	ZNS	FES2	CAL/DCL
28	552	0.550	0.678	0.549	0.635
35	419	0.302	0.624	0.445	0.583
48	296	0.414	0.484	0.334	0.413
65	209	0.295	0.331	0.240	0.306
100	148	0.194	0.186	0.127	0.190
150	105	0.116	.124	0.069	0.156
200	74	0.074	0.073	0.050	0.095
270	53	0.050	0.042	0.032	0.060
400	37	0.037	0.033	0.025	0.046

```
C
C        PROGRAM TO SIMULATE A CLOSED CIRCUIT OF
C        GRINDING (OVERALL PERFORMANCE)
C
C        THIS IS AN ITERATIVE PROGRAM. STEADY STATE
C        FLOW RATE CONDITIONS ARE SIMULATED.  IT
C        USES LABORATORY GRINDING KINETICS DATA.
C        THE SO-CALLED "F-ORDER MODEL".
C
C        NOMENCLATURE
C        ------------
C
C        INPUT DATA
C        ----------
C
C        SIZ1(I) - -    SIZE ASSAYS OF STREAM 1 (RMD).
C                       PERCENT.  INDEX I IS MESH NO.
C
C        Y(I) - -       CYCLONE SELECTIVITY INDEX.
C                       THE PERCENT OF CYCLONE FEED
C                       DIVERTED TO THE UNDERFLOW.
C
C        B(I) -         THE RATE OF BREAKAGE OF THE ORE
C                       DETERMINED IN LAB EXPERIMENTS
C                       DETERMINED FROM LAB EXPERIMENTS
C                                 -P(I)
C                       UNITS: MIN
C
C        P(I) -         ORDER OF BREAKAGE,DETERMINED FROM
C                       LABORATORY EXPERIMENTS.
C
C        BMH -          VOLUMETRIC BALL MILL HOLDUP,
C                       CUBIC METERS
C
C        SOL1 -         FRESH FEED MASS FLOW RATE TO
C                       THE GRINDING CIRCUIT. MET TONNE/HR
C        RHO -          SPECIF GRAVITY OF MATERIAL IN
C                       BALL MILL FEED. MET TONNE/
C                       CUBIC METERS
C
C        CALCULATED PARAMETERS
C        ---------------------
C
C        TIME -         BALL MILL RESIDENCE TIME. MIN
C        CL -           OVERALL CIRCULATING LOAD. PCT
C        PCTS1 -        PERCENT SOLIDS BY WT IN STREAM 1
C        PCTS2,PCTS3,PCTS4 AND PCTS5 - PERCENT SOLIDS,
C                       BY WT IN STREAMS 2 TO 5
C
C        SIZ1(I) TO SIZ5(I) - SIZE ASSAYS IN STREAMS
C                       2 TO 5, RESPECTIVELY
C        FSIZ1(I) TO FSIZ5(I) -  CUMULATIVE WT PCT FINER IN
C                       STREAMS 1 TO 5, RESPECTIVELY.
C
      DIMENSION SIZ1(10),SIZ2(10),SIZ3(10),SIZ4(10),SIZ5(10)
      DIMENSION CSIZ1(10),CSIZ2(10),CSIZ3(10),CSIZ4(10),CSIZ5(10)
      DIMENSION FSIZ1(10),FSIZ2(10),FSIZ3(10),FSIZ4(10),FSIZ5(16)
      DIMENSION B(10),P(10),Y(10),MESH(10),LAPERT(10)
      REAL MIT,MTT
```

```
      READ(5,1)(SIZ1(I),I=1,10)
      READ(5,1)(Y(I),I=1,10)
      READ(5,2)(B(I),I=1,9)
      READ(5,2)(P(I),I=1,9)
      READ(5,3)(MESH(I),I=1,10)
      READ(5,3)(LAPERT(I),I=1,10)
      READ(5,4)BMH,SCL1,RHC
    1 FORMAT(10F5.2)
    2 FORMAT(9F7.4)
    3 FORMAT(10I4)
    4 FORMAT(F6.4,1X,F6.2,1X,F4.2)
      PF= 34.00
      PCTS1= 77.00
      VW1= ((100.*(SCL1/PCTS1) - SCL1)/60.
      VW5= 210./60.
      TON= 6.E5/SCL1
      UNIT= 1./TON
      MIT= 1.E4
      RHO1= RHC*TON
      SUM1= 0.0
      DO 10 I=1,10
      CSIZ1(I)= SUM1 + SIZ1(I)*100.
      SUM1= CSIZ1(I)
      SIZ5(I)= 0.0
   10 CONTINUE
      M= 1
   15 DO 50 I=1,10
      SIZ2(I)= SIZ1(I)*100. + SIZ5(I)
   50 CONTINUE
      SUM= 0.0
      DO 60 I=1,10
      CSIZ2(I)= SUM + SIZ2(I)
      SUM= CSIZ2(I)
   60 CONTINUE
      VW2= VW1 + VW5
      VW4= PF*VW2/100.
      VW3= VW2 - VW4
      DO 70 I=1,10
      SIZ4(I)= SIZ2(I)*Y(I)/100.
      SIZ3(I)= SIZ2(I) - SIZ4(I)
   70 CONTINUE
      SUM= 0.0
      SUM1= 0.0
      DO 80 I=1,10
      CSIZ3(I)= SUM1 + SIZ3(I)
      CSIZ4(I)= SUM + SIZ4(I)
      SUM1= CSIZ3(I)
      SUM= CSIZ4(I)
   80 CONTINUE
      VSOL4= CSIZ4(10)/RHO1
      TIME= BMH/(VSOL4 + VW4)
      DO 90 I=1,9
      CSIZ5(I)= CSIZ4(I)*EXP(-B(I)*TIME**P(I))
   90 CONTINUE
      CSIZ5(10)= CSIZ4(10)
      DO 100 I=2,10
      L= I - 1
      SIZ5(I)= CSIZ5(I) - CSIZ5(L)
  100 CONTINUE
      SIZ5(1)= CSIZ5(1)
```

```
      M3T= CSIZ3(10)
      A= ABS(M1T - M3T)
      IF((A.LE.1.0).OR.(M.EQ.50))GO TO 110
      M= M + 1
      GO TO 15
  110 CL= CSIZ4(10)/M1T*100.
      PCTS2= CSIZ2(10)*UNIT/(CSIZ2(10)*UNIT + VW2)*100.
      PCTS3= CSIZ3(10)*UNIT/(CSIZ3(10)*UNIT + VW3)*100.
      PCTS4= CSIZ4(10)*UNIT/(CSIZ4(10)*UNIT + VW4)*100.
      PCTS5= PCTS4
      S1= 0.00
      S2= 0.00
      S3= 0.00
      S4= 0.00
      S5= 0.00
      DO 120 I=1,10
      SIZ2(I)= 100.*SIZ2(I)/CSIZ2(10)
      SIZ3(I)= 100.*SIZ3(I)/CSIZ3(10)
      SIZ4(I)= 100.*SIZ4(I)/CSIZ4(10)
      SIZ5(I)= 100.*SIZ5(I)/CSIZ5(10)
      CSIZ1(I)= S1 + SIZ1(I)
      CSIZ2(I)= S2 + SIZ2(I)
      CSIZ3(I)= S3 + SIZ3(I)
      CSIZ4(I)= S4 + SIZ4(I)
      CSIZ5(I)= S5 + SIZ5(I)
      S1= CSIZ1(I)
      S2= CSIZ2(I)
      S3= CSIZ3(I)
      S4= CSIZ4(I)
      S5= CSIZ5(I)
      FSIZ1(I)= 100. - CSIZ1(I)
      FSIZ2(I)= 100. - CSIZ2(I)
      FSIZ3(I)= 100. - CSIZ3(I)
      FSIZ4(I)= 100. - CSIZ4(I)
      FSIZ5(I)= 100. - CSIZ5(I)
  120 CONTINUE
      WRITE(6,200)M,SCL1,BMH,TIME,CL,PCTS1,PCTS2,PCTS3,PCTS4,PCTS5
      WRITE(6,210)
      DO 130 I=1,10
      WRITE(6,220)MESH(I),LAPERT(I),SIZ1(I),SIZ2(I),SIZ3(I),SIZ4(I),
     *SIZ5(I),FSIZ1(I),FSIZ2(I),FSIZ3(I),FSIZ4(I),FSIZ5(I),E(I),P(I),
     *Y(I)
  130 CONTINUE
  200 FORMAT('1'//////////15X,'ITERATION NO:',I3/15X,'INPUT TONNAGE:',
     *F7.2,' METRIC TONS/HR'/15X,'BALL MILL HOLDUP:',F7.2,' CUBIC METER
     *S'/15X,'RESIDENCE TIME:',F5.2,' MINUTES'/15X,'CIRCULATING LOAD:',
     *F6.2,' %'/15X,'PCTS1:',F6.2,' %'/15X,'PCTS2:',F6.2,' %'/15X,
     *'PCTS3:',F6.2,' %'/15X,'PCTS4:',F6.2,' %'/15X,'PCTS5:',F6.2,' %')
  210 FORMAT(/////12X,'MESH',2X,'SIZE',3X,'PCT 1 PCT 2 PCT 3 PCT 4 PCT 5
     *     CUMF1 CUMF2 CUMF3 CUMF4 CUMF5   RATE B.  EFD  P  INDEX Y'//)
  220 FORMAT(12X,I4,2X,I4,2X,5F6.2,3X,5F6.2,3X,F6.4,2X,F6.4,2X,F6.2//)
      STOP
      END

$DATA
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C
C       PROGRAM TO SIMULATE A CLOSED CIRCUIT OF
C       GRINDING (OVERALL PERFORMANCE)
C
C       THIS IS AN ITERATIVE PROGRAM.  STEADY STATE
C       FLOW RATE CONDITIONS ARE SIMULATED.  IT
C       USES LABORATORY GRINDING KINETICS DATA.
C       THE SO-CALLED 'P-ORDER MODEL'.
C
C    THIS PROGRAM UTILISES A GRINDING MODEL AS DESCRIBED
C       PREVIOUSLY. IT CONSIDERS A FREQUENCY TIME DISTRI-
C       BUTION GIVEN BY SUBDIVIDING THE BALL MILL INTO
C       THREE 'TANKS' IN SERIES.  THE FIRST ONE IS A
C       PLUG FLOW MILL. THE OTHER TWO ARE FULLY-MIXED MILLS.
C
C       RESIDENCE TIME OF 1ST MILL= 0.20 MEAN RESIDENCE TIME
C       RESIDENCE TIME OF 2ND MILL= 0.40 MEAN RESIDENCE TIME
C       RESIDENCE TIME OF THIRD MILL= 0.40 MEAN RESIDENCE TIME
C
C
C       NOMENCLATURE
C
C       ------------
C
C       INPUT DATA
C
C       ----------
C
C       SIZ1(I) -       SIZE ASSAYS OF STREAM 1 (RMD).
C                       PERCENT.  INDEX I IS MESH NO.
C
C       Y(I) - -        CYCLONE SELECTIVITY INDEX.
C                       THE PERCENT OF CYCLONE FEED
C                       DIVERTED TO THE UNDERFLOW.
C
C       B(I) -          THE RATE OF BREAKAGE OF THE ORE
C                       DETERMINED IN LAB EXPERIMENTS
C                       DETERMINED FROM LAB EXPERIMENTS
C                                  -P(I)
C                       UNITS: MIN
C
C       P(I) -          ORDER OF BREAKAGE.DETERMINED FROM
C                       LABORATORY EXPERIMENTS.
C
C       BMH -           VOLUMETRIC BALL MILL HOLDUP.
C                       CUBIC METERS
C
C       SOL1 -          FRESH FEED MASS FLOW RATE TO
C                       THE GRINDING CIRCUIT. MET TONNE/HR
C       RHO -           SPECIF GRAVITY OF MATERIAL IN
C                       BALL MILL FEED. MET TONNE/
C                       CUBIC METERS
C
C       CALCULATED PARAMETERS
C
C       ---------------------
C
C       TIME -          BALL MILL RESIDENCE TIME. MIN
C       CL -            OVERALL CIRCULATING LOAD. PCT
C       PCTS1 -         PERCENT SOLIDS BY WT IN STREAM 1
C       PCTS2,PCTS3,PCTS4 AND PCTS5 - PERCENT SOLIDS
C                       BY WT IN STREAMS 2 TO 5
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C
C     SIZ1(I) TO SIZ5(I) - SIZE ASSAYS IN STREAMS
C                 ? TO ?, RESPECTIVELY
C     FSIZ1(I) TO FSIZ5(I) -  CUMULATIVE WT PCT FINER IN
C                 STREAMS 1 TO 5, RESPECTIVELY.
C
      DIMENSION SIZ1(10),SIZ2(10),SIZ3(10),SIZ4(10),SIZ5(10)
      DIMENSION CSIZ1(10),CSIZ2(10),CSIZ3(10),CSIZ4(10),CSIZ5(10)
      DIMENSION FSIZ1(10),FSIZ2(10),FSIZ3(10),FSIZ4(10),FSIZ5(10)
      DIMENSION B(10),P(10),Y(10),MESH(10),LAPERT(10)
      REAL MIT,M3T
      READ(5,1)(SIZ1(I),I=1,10)
      READ(5,1)(Y(I),I=1,10)
      READ(5,2)(B(I),I=1,9)
      READ(5,2)(P(I),I=1,9)
      READ(5,3)(MESH(I),I=1,10)
      READ(5,3)(LAPERT(I),I=1,10)
      READ(5,4)EMF,SOL1,RHO
    1 FORMAT(10F6.2)
    2 FORMAT(9F7.4)
    3 FORMAT(10I4)
    4 FORMAT(F6.4,1X,F6.2,1X,F4.2)
      AT= [illegible].2[illegible]
      BT= [illegible].49
      CT= [illegible].4[illegible]
      RF= 34.[illegible]
      PCTS1= 77.[illegible]
      VW1= ((100.*SOL1/PCTS1) - SOL1)/60.
      VW5= 21[illegible]./60.
      TON= 6.E5/SOL1
      UNIT= 1./TON
      MIT= 1.E4
      RHO1= RHO*TON
      SUM1= [illegible]
      DO 10 I=1,10
      CSIZ1(I)= SUM1 + SIZ1(I)*10[illegible].
      SUM1= CSIZ1(I)
      SIZ5(I)= [illegible]
   10 CONTINUE
      N= 1
   15 DO 50 I=1,10
      SIZ2(I)= SIZ1(I)*1[illegible]. + SIZ5(I)
   50 CONTINUE
      SUM= [illegible]
      DO 60 I=1,1[illegible]
      CSIZ2(I)= SUM + SIZ2(I)
      SUM= CSIZ2(I)
   60 CONTINUE
      VW2= VW1 + VW5
      VW4= RF*VW2/10[illegible].
      VW3= VW2 - VW4
      DO 70 I=1,1[illegible]
      SIZ4(I)= SIZ2(I)*Y(I)/10[illegible].
      SIZ3(I)= SIZ2(I) - SIZ4(I)
   70 CONTINUE
      SUM= [illegible]
      SUM1= [illegible]
      DO 6[illegible] I=1,1[illegible]
      CSIZ3(I)= SUM1 + SIZ3(I)
      CSIZ4(I)= SUM + SIZ4(I)
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      SUM1= CSIZ3(I)
      SUM= CSIZ4(I)
   80 CONTINUE
      VSOL4= CSIZ4(10)/RHCI
      TIME= BMH/(VSOL4 + VW4)
      CALL GRMILL(B,P,TIME,AT,HT,CT,CSIZ4,CSIZ5)
      CSIZ5(1 )= CSIZ4(1)
      DO 100 I=2,10
      L= I - 1
      SIZ5(I)= CSIZ5(I) - CSIZ5(L)
  100 CONTINUE
      SIZ5(1)= CSIZ5(1)
      M3T= CSIZ3(10)
      A= ABS(M1T - M3T)
      IF((A.LE.1).).OR.(M.EQ.50))GO TO 110
      M= M + 1
      GO TO 15
  110 CL= CSIZ4(10)/M1T*100.
      PCTS2= CSIZ2(10)*UNIT/(CSIZ2(10)*UNIT + VW2)*100.
      PCTS3= CSIZ3(10)*UNIT/(CSIZ3(10)*UNIT + VW3)*100.
      PCTS4= CSIZ4(10)*UNIT/(CSIZ4(10)*UNIT + VW4)*100.
      PCTS5= PCTS4
      S1= 0.0
      S2= 0.0
      S3= 0.0
      S4= 0.0
      S5= 0.0
      DO 120 I=1,10
      SIZ2(I)= 100.*SIZ2(I)/CSIZ2(10)
      SIZ3(I)= 100.*SIZ3(I)/CSIZ3(10)
      SIZ4(I)= 100.*SIZ4(I)/CSIZ4(10)
      SIZ5(I)= 100.*SIZ5(I)/CSIZ5(10)
      CSIZ1(I)= S1 + SIZ1(I)
      CSIZ2(I)= S2 + SIZ2(I)
      CSIZ3(I)= S3 + SIZ3(I)
      CSIZ4(I)= S4 + SIZ4(I)
      CSIZ5(I)= S5 + SIZ5(I)
      S1= CSIZ1(I)
      S2= CSIZ2(I)
      S3= CSIZ3(I)
      S4= CSIZ4(I)
      S5= CSIZ5(I)
      FSIZ1(I)= 100. - CSIZ1(I)
      FSIZ2(I)= 100. - CSIZ2(I)
      FSIZ3(I)= 100. - CSIZ3(I)
      FSIZ4(I)= 100. - CSIZ4(I)
      FSIZ5(I)= 100. - CSIZ5(I)
  120 CONTINUE
      WRITE(6,200)M,SOL1,BMH,TIME,CL,PCTS1,PCTS2,PCTS3,PCTS4,PCTS5
      WRITE(6,210)
      DO 130 I=1,10
      WRITE(6,220)MESH(I),LABELT(I),SIZ1(I),SIZ2(I),SIZ3(I),SIZ4(I),
     #SIZ5(I),FSIZ1(I),FSIZ2(I),FSIZ3(I),FSIZ4(I),FSIZ5(I),B(I),P(I),
     #Y(I)
  130 CONTINUE
  200 FORMAT('1'//////////15X,'ITERATION NO:',I3/15X,'INPUT TONNAGE:',
     #F7.2,'  METRIC TONS/HR'/15X,'BALL MILL HOLDUP:',F7.2,' CUBIC METER
     #S'/15X,'RESIDENCE TIME:',F5.2,' MINUTES'/15X,'CIRCULATING LOAD:',
     #F8.2,' %'/15X,'PCTS1:',F6.2,' %'/15X,'PCTS2:',F6.2,' %'/15X,
     #'PCTS3:',F6.2,' %'/15X,'PCTS4:',F6.2,' %'/15X,'PCTS5:',F6.2,' %')
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```
210  FORMAT(/////12X,'MESH',2X,'SIZE',3X,'PCT 1 PCT 2 PCT 3 PCT 4 PCT 5
    $    CUMF1 CUMF2 CUMF3 CUMF4 CUMF5    RATE B   CHD   P   INDEX Y'//)
220  FORMAT(12X,I4,2X,I4,2X,5F6.2,3X,5F6.2,3X,F6.4,2X,F6.4,2X,F6.2//)
     STOP
     END

     SUBROUTINE GRMILL(B,P,TIME,A,B1,C,CUMC4,CUMC5)
     DIMENSION B(10),P(10),CUMC4(10),CUMC5(10)
     DIMENSION CA(10),CB(10)
     TIMEA= A*TIME
     TIMEB= B1*TIME
     TIMEC= TIME*C
     DO 10 I=1,5
     CA(I)= CUMC4(I)*EXP(-B(I)*TIMEA**P(I))
     CB(I)= CA(I)*(1./(1. + B(I)*TIMEB** P(I)))
     CUMC5(I)= CB(I)*(1./(1. + B(I)*TIMEC**P(I)))
10   CONTINUE
     RETURN
     END

$DATA
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ITERATION NO: 14
INPUT TONNAGE: 154.20 METRIC TONS/HR
BALL MILL HOLDUP: 8.37 CUBIC METERS
RESIDENCE TIME: 3.27 MINUTES
CIRCULATING LOAD: 156.90 %
PCTS1: 77.00 %
PCTS2: 61.73 %
PCTS3: 47.69 %
PCTS4: 73.54 %
PCTS5: 73.54 %

MESH	SIZE	PCT 1	PCT 2	PCT 3	PCT 4	PCT 5	CUMF1	CUMF2	CUMF3	CUMF4	CUMF5	RATE B	CHG F	INDEX
28	600	19.42	9.04	0.25	14.65	2.43	80.58	90.96	99.75	85.35	97.57	0.7106	0.7843	98.94
35	425	7.96	3.83	0.42	6.00	1.20	72.62	87.13	99.34	79.35	96.38	0.5802	0.9281	95.77
48	300	7.39	5.19	0.69	7.89	1.62	65.23	82.14	98.65	71.46	92.75	0.3816	1.0806	94.72
65	212	5.72	6.12	2.39	8.50	6.38	59.51	75.92	96.26	62.96	86.37	0.2757	1.0808	84.83
100	150	7.62	11.31	7.44	13.76	13.65	51.89	64.61	88.82	49.20	72.72	0.1749	1.0719	74.36
150	106	9.05	14.40	13.35	15.06	17.81	42.84	51.22	75.47	34.14	54.92	0.1056	1.1485	63.91
200	75	8.15	14.07	13.48	12.81	16.20	34.69	37.15	61.99	21.33	38.71	0.0741	1.0264	59.87
270	53	8.66	10.93	16.02	7.68	12.37	26.03	26.22	45.97	13.65	26.34	0.0461	1.0466	42.96
400	38	5.38	5.59	9.15	3.32	5.72	20.65	20.64	36.83	10.33	20.62	0.0363	1.0474	36.29
-400	-38	20.66	20.64	36.83	10.33	20.62	-0.01	0.00	-0.00	0.00	0.00	UUUUUU	UUUUUU	29.57

ITERATION NO: 15
INPUT TONNAGE: 154.20 METRIC TONS/HR
BALL MILL HOLDUP: 8.37 CUBIC METERS
RESIDENCE TIME: 3.19 MINUTES
CIRCULATING LOAD: 164.97 %
PCTS1: 77.00 %
PCTS2: 61.47 %
PCTS3: 47.69 %
PCTS4: 74.50 %
PCTS5: 74.50 %

MESH	SIZE	PCT. 1	PCT 2	PCT 3	PCT 4	PCT 5	CUMF1	CUMF2	CUMF3	CUMF4	CUMF5	RATE B	ORD P	INDEX Y
28	600	15.42	8.87	0.25	14.09	2.47	60.58	91.13	99.75	85.91	97.53	0.7106	0.7843	98.94
35	425	7.56	4.44	0.50	6.83	2.31	72.62	86.69	99.25	79.08	95.23	0.5802	0.9281	95.77
48	300	7.20	6.02	0.93	10.06	6.15	65.23	81.08	98.33	69.02	89.08	0.3816	1.0[illegible]	94.72
65	212	5.72	6.79	2.73	9.25	7.44	59.51	73.29	95.6[illegible]	59.77	81.04	0.2757	1.0898	84.83
100	150	7.62	11.42	7.75	13.04	13.72	51.89	61.87	87.84	46.13	67.91	0.1749	1.0719	74.38
150	106	9.05	13.76	13.16	14.12	16.62	42.84	48.11	74.68	32.01	51.30	0.1096	1.0485	63.91
200	75	9.15	12.26	13.64	11.79	14.75	34.65	35.85	61.04	20.22	36.54	0.0741	1.02[illegible]	59.87
270	53	8.00	10.73	16.22	7.40	11.96	26.03	25.12	45.42	12.82	24.56	0.0461	1.0460	42.96
400	38	5.38	5.36	9.05	3.12	5.35	21.65	19.76	36.37	9.70	19.21	0.0353	1.0474	36.29
-400	-38	2[illegible].6[illegible]	19.7[illegible]	36.37	6.70	19.21	-0.01	0.00	-0.0[illegible]	0.00	0.00	0.0000	0.0000	3[illegible].57