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CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

SPOC

Simulated Processing of Ore and Coal

Chapter 5.2 Unit Models (Part C)

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The SPOC Manual

Chapter 5.2 Unit Models (Part C)

Unit Models and FORTRAN Simulators of Ore and Coal Process Equipment: Miscellaneous

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THE SPOC MANUAL

The **SPOC*** manual consists of eighteen chapters, published separately. Their numbers and short titles are as follows:

1. Summary
2. Sampling Methodology

2.1 SAMBA Computer Program
2.2 Grinding Circuit Sampling
3. Material Balance

3.1 BILMAT Computer Program
3.2 MATBAL Computer Program
4. Modelling and Simulation

4.1 Industrial Ball Mill Modelling
5. Unit Models: Part A

5.1 Unit Models: Part B
5.2 Unit Models: Part C
6. Flowsheet Simulators
7. Model Calibration

7.1 STAMP Computer Program
7.2 FINDBS Computer Program
7.3 RTD and MIXERS Computer Programs
8. Miscellaneous Computer Programs

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Ottawa, Ontario

*Simulated Processing of Ore and Coal

FOREWORD

High energy costs and depleting ore reserves combine to make process evaluation and optimization a challenging goal in the 80's. The spectacular growth of computer technology in the same period has resulted in widely available computing power that can be distributed to the most remote mineral processing operations. The SPOC project, initiated at CANMET in 1980, has undertaken to provide Canadian industry with a coherent methodology for process evaluation and optimization assisted by computers. The SPOC Manual constitutes the written base of this methodology and covers most aspects of steady-state process evaluation and simulation. It is expected to facilitate industrial initiatives in data collection and model upgrading.

Creating a manual covering multidisciplinary topics and involving contributions from groups in universities, industry and government is a complex endeavour. The reader will undoubtedly notice some heterogeneities resulting from the necessary compromise between ideals and realistic objectives or, more simply, from oversight. Critiques to improve future editions are welcomed.

D. Laguitton
SPOC Project Leader
Canada Centre for Mineral and Energy Technology

AVANT-PROPOS

La croissance des coûts de l'énergie et l'appauvrissement des gisements ont fait de l'évaluation et de l'optimisation des procédés un défi des années 80 au moment même où s'effectuait la dissémination de l'informatique jusqu'aux concentrateurs les plus isolés. Le projet SPOC, a été lancé en 1980 au CANMET, en vue de développer pour l'industrie canadienne, une méthodologie d'application de l'informatique à l'évaluation et à l'optimisation des procédés minéralurgiques. Le Manuel SPOC constitue la documentation écrite de cette méthodologie et en couvre les différents éléments. Les retombées devraient en être une vague nouvelle d'échantillonnages et d'amélioration de modèles.

La rédaction d'un ouvrage couvrant différentes disciplines et rassemblant des contributions de groupes aussi divers que les universités, l'industrie et le gouvernement est une tâche complexe. Le lecteur notera sans aucun doute des ambiguïtés ou contradictions qui ont pu résulter de la diversité des sources, de la traduction ou tout simplement d'erreurs. La critique constructive est encouragée afin de parvenir au format et au contenu de la meilleure qualité possible.

D. Laguitton
Chef du projet SPOC,
Centre canadien de la technologie des minéraux et de l'énergie

ABSTRACT

This chapter of the *SPOC Manual* describes seven process simulators: RMILL, BMILL, MOGENS, BALDRM, VACFIL, MIXER2 or MIXER3, and EXTRAP.

RMILL simulates a rod mill according to the Lynch-Callcott model using breakage and selection functions. BMILL is the kinetic model of ball milling which simulates the grinding of particles by quantifying the size distribution of the ground product, the rate of breakage, and the residence time of particles in the mill. MOGENS simulates the operation of a linear, multi-deck probability screening machine known as the Mogensen Sizer. BALDRM is the mathematical simulator of an industrial balling drum circuit. VACFIL simulates the operation of a rotary vacuum filter during steady-state operations based on its operational parameters. MIXER2 or MIXER3 simulates the mixing of two or three flows. EXTRAP simulates the extrapolation of a size distribution in the fine size range.

RÉSUMÉ

Ce chapitre du *Manuel SPOC* décrit sept simulateurs de procédé soit: RMILL, BMILL, MOGENS, BALDRM, VACFIL, MIXER2 ou MIXER3 et EXTRAP.

Le RMILL simule un broyeur à barres suivant le modèle Lynch-Callcott à l'aide des fonctions de broyage et de sélection. Le BMILL est un modèle cinétique d'un broyeur à boulets; il simule le broyage des particules en évaluant quantitativement la granulométrie du produit broyé, la vitesse de broyage et le temps de séjour des particules dans le broyeur. Le MOGENS simule le fonctionnement d'un crible linéaire à plusieurs étages connu sous le nom de calibreur Mogensen. Le BALDRM est un simulateur mathématique d'un circuit à tambour bouleteur industriel. Le VACFIL simule le fonctionnement d'un filtre à vide rotatif au cours des opérations à régime permanent, d'après ses paramètres de fonctionnement. Le MIXER2 ou MIXER3 simule le mélange de deux ou trois écoulements. L'EXTRAP simule l'extrapolation d'une granulométrie dans la gamme de dimensions fines.

ACKNOWLEDGEMENTS

The SPOC project has benefited from such a wide range of contributions throughout the industry, the university, and the government sectors that a nominal acknowledgement would be bound to make unfair omissions. The main groups that contributed are: the various contractors who completed project elements; the Industrial Steering Committee members who met seven times to provide advice to the project leader; the various users of project documents and software who provided feedback on their experience; the CANMET Mineral Sciences Laboratories staff members who handled the considerable in-house task of software development, maintenance, and documentation; the EMR Computer Science Centre staff who were instrumental in some software development; and the CANMET Publications Section. Inasmuch as in a snow storm, every flake is responsible, their contributions are acknowledged.

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1. ROD MILL (RMILL)

1.1 PROGRAM IDENTIFICATION

Program Title:	Simulation of a **R**od **MILL**.
Program Code Name:	RMILL.
Authors:	D. Laguitton, F. Flament, from Lynch and Callcott model.
Organization:	Energy, Mines and Resources Canada, Canada Centre for Mineral and Energy Technology, Mineral Processing Laboratory.
Date:	July 1985.
Updates:	None.
Source Language:	CDC FORTRAN Extended 4.8 (American National Standard Institute FORTRAN X3.9 — 1966).
Availability:	Complete program listing is available from: CANMET, Energy, Mines and Resources Canada, Technology Information Division, 555 Booth Street, Ottawa, Ontario, K1A 0G1.

1.2 ENGINEERING DOCUMENTATION

1.2.1 Narrative Description

Rod mills are large tumbling mills in which the grinding media consists of steel rods occupying up to 45% of the inner shell volume as shown in Figure 1.1. The rod diameter varies between 4 and 15 cm. Rod mills are often used as initial wet grinding devices in concentrators where the crushing plant product is minus 5 cm and more often 1 to 80 cm in mean size. The length-to-diameter ratio is between 1.3 and 1.5, the usual speed is 70 to 75% of the critical speed, i.e., the speed at which particles would start centrifuging on the inner shell. In practice, the mills are operated at 20 to 30 rpm. The reader is referred to general or commercial literature for detailed discussions of rod-mill construction and operation (1).

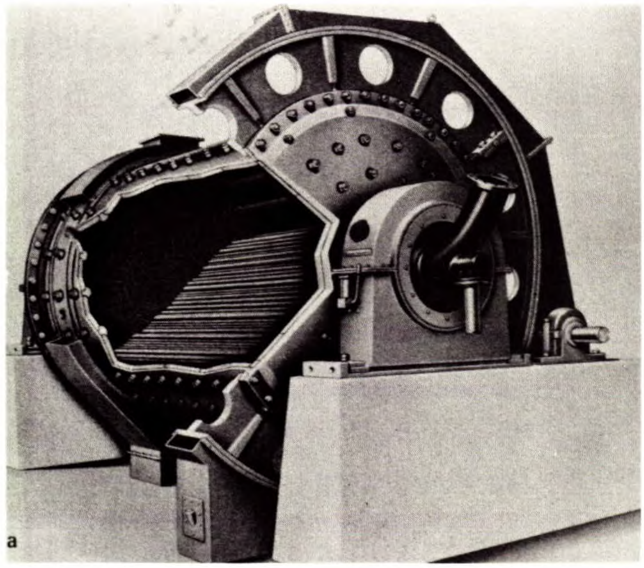

Fig. 1.1 — Exploded view of a rod mill (Courtesy Allis-Chalmers)

1.2.2 Method of Solution

The rod-mill model adapted as the SPOC module is the Callcott-Lynch model as published by Lynch (2). The model description presented below is therefore a summary of the original document. More recently, a simplified rod-mill model has been published by Gupta (3).

In summary, the Lynch model describes the mill as a series of breakage stages in which the largest sieve fraction from the mill feed in the first stage, and from the discharge of the previous stage in the subsequent stages, is eliminated. The number of stages is related to the feed rate by the following equation:

$$F \times V^{1.5} = \text{constant}$$

The constant is called mill constant and constitutes one of the model parameters. F is the mill feed rate in t/h and V the number of stages.

The general model equation is:

$$P = \left[\prod_{j=1}^{j=v} X_j. \right] f$$

and $X_j = (I - C)(BS + I - S)[I - C(BS + I - S)]^{-1} f$

where π indicates a product $\prod_{j=1}^{j=v} = X_V \ldots X_3 X_2 X_1$

- I is the identity matrix
- f is feed
- X_j is the transformation matrix from stage j to J + 1
- C is a classification vector containing 1 as the first value, zeroes for the remaining positions

B and S are the breakage and selection functions.

The breakage function is the characteristic size distribution of particles produced from a mother size fraction. The selection function is the probability of breakage of a mother size fraction.

1.3 PROGRAM AND SUBROUTINES

1.3.1 Program XRMILL

1.3.1.1 Purpose

To read a default data file (unit #5) and modify data as required using subroutines RDFILE and UDRIVR; to call the simulator subroutine RMILL and the output routines RMOUT and PLOTSZ.

1.3.1.2 Usage

Execute as a main program.

1.3.1.3 Variables to be read

NS = number of size intervals.
NG = number of specific gravity intervals (=1).
NC = number of characteristics (=1).
SRI = mass flow rate of solids in feed (tonnes/h).
WRI = mass flow rate of water in feed (tonnes/h).
SIZI = size distribution of feed (cum. weight fraction passing).
PARAM = parameter vector
  1: RMC
  2 to (NS+1): BRM
  (NS+2) to (NS+1): SRM.
RMC = rod mill constant.
BRM = breakage function vector of the ore.
SRM = selection function of mill.
OPT = option vector
  1: PRINT.
PRINT = print option
  0: short output
  1: complete output.
XMU = sieve size vector (micrometres).
SG = specific gravity vector (not used in this simulator).

1.3.2 Subroutine RMILL

1.3.2.1 Purpose

To simulate a rod mill.

1.3.2.2 Usage

CALL RMILL (NS, NG, NC, SRI, WRI, SIZI, SRO, WRO, SIZO, SOL3, WAT3, CH3, SOL4, WAT4, CH4, DER1, DER2, DER3, PARAM, OPT).

1.3.2.3 Parameters list

NS, NG, NC, SRI, WRI, SIZI, PARAM, OPT } are defined in Section 1.3.1

SOLi = solids flow rate for i from 3 to 4 (unused in this model).
WATi = water flow rate for i from 3 to 4 (unused in this model).
CHi = three-dimensional array of characteristic 'assays' for i from 3 to 4 (unused in this model).
DERi = derivative vector for i from 1 to 3 (unused in this model).
SRO = mass flow rate of solids in product (tonnes/h).
WRO = mass flow rate of water in product (tonnes/h).
SIZO = size distribution of product (non-cumulative weight per cent).

1.3.2.4 Subroutines and functions required

CUMP, NCUMP.

1.3.3 Subroutine RMOUT

1.3.3.1 Purpose

To print the output of the RMILL simulator including a line plot of the feed and product vectors using subroutine PLOTSZ.

1.3.3.2 Usage

CALL RMOUT (NS, NG, NC, SRI, WRI, SIZI, SRO, WRO, SIZO, SOL3, WAT3, CH3, SOL4, WAT4, CH4, DER1, DER2, DER3, PARAM, OPT).

1.3.3.3 Parameters list

As defined in Section 1.3.2.

Note: For details of subroutines RDFILE, UDRIVR, PLOTSZ, CUMP and NCUMP, see Chapters 5 and 5.1 of the SPOC Manual.

1.4 SAMPLE RUN

As an example, the rod-mill simulation discussed on page 75 of Lynch's manual (2) is presented below.

```
             SIMULATION OF A ROD MILL (RMILL)
             --------------------------------

    PROGRAM
    DESCRIPTION:  THIS IS THE CLASSICAL LYNCH-CALLCOTT MATRIX
    -----------   MODEL USING BREAKAGE AND SELECTION FUNCTIONS.


    THE PROGRAMS AND SUBROUTINES ARE:
    --------------------------------

       XRMILL,RDFILE,NCUMP,UDRIVR,RMILL,RMOUT,CUMP,CUMR,
       PLOTSZ,INITGR


    THE VARIABLES REQUIRED ARE AS FOLLOWS:
    -------------------------------------

     NS     = NUMBER OF SIZE FRACTIONS (PAN INCLUDED)
     NG     = NUMBER OF SPECIFIC GRAVITY FRACTIONS
     NC     = NUMBER OF CHARACTERISTICS
     SOL    = MASS FLOW RATE OF SOLIDS IN FEED
     WAT    = MASS FLOW RATE OF WATER IN FEED

     FEED   = SIZI = SIZE DISTRIBUTION OF THE FEED IN
                         CUM. PASS. W.F.

     PARAM  = PARAMETER VECTOR - 1 = RMC
                          2 TO (1+NS) = BRM
                 (2+NS) TO (1+2*NS) = SRM
     RMC    = ROD MILL CONSTANT
     BRM    = BREAKAGE FUNCTION VECTOR OF THE ORE
     SRM    = SELECTION FUNCTION OF MILL

     OPT    = OPTION VECTOR    - 1 = PRINT
     PRINT  = PRINT OPTION (0 FOR SHORT OUTPUT, 1 FOR COMPLETE
              OUTPUT)

     XMU    = SCREEN SIZE VECTOR


              DATA ENTRY FOR : RMILL


 THE DEFAULT VALUES OF NS,NG,NC,SOL & WAT ARE:

10 1 1 106. 106.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
.009999999999998 .028 .31 .226 .142 .086 .054 .041 .017 .086

 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
550. .198 .3308 .2148 .1225 .0654 .0338 .0172 .0083 .0043 .0049
1. .8 .25 .2 .25 .5 .5 .5 .5 0.
```

```
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE OPTIONS  RELATED TO THIS SIMULATOR ARE:
1.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SIZES ARE:

19020. 9510. 4755. 2378. 1189. 594. 297. 149. 74. 37.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SPECIFIC GRAVITIES ARE:
0.
 CHANGE?(Y/N)
n
```

```
                           ROD MILL OUTPUT (RMILL)



                                   ____
                                  !    !___________________
                                  !    !                   !
                                  !    !     ROD MILL      !
     SFR=  106.00               --!    !                   !--  SFR=  106.00
     WFR=  106.00                 !    !                   !    WFR=  106.00
      %S=   50.00               --!    !    3.0 STAGES     !--   %S=   50.00
                                  !    !                   !
                                  !    !___________________!
                                  !____!
TO CONTINUE, ENTER ANY DIGIT AND <CR>0
```

ROD MILL UNIT

SCREENS	FEED %CUM	FEED %RET	PRODUCT %CUM	PRODUCT %RET
38040.-19020.	100.000	1.000	100.000	0.000
19020.- 9510.	99.000	2.800	100.000	0.000
9510.- 4755.	96.200	31.000	100.000	.028
4755.- 2378.	65.200	22.600	99.972	13.024
2378.- 1189.	42.600	14.200	86.948	24.378
1189.- 594.	28.400	8.600	62.570	17.045
594.- 297.	19.800	5.400	45.525	10.906
297.- 149.	14.400	4.100	34.619	7.103
149.- 74.	10.300	1.700	27.515	5.647
74.- 0.	8.600	8.600	21.868	21.868

```
     SOLID FLOW RATE :     106.000
     WATER FLOW RATE :     106.000
     NO. OF STAGES   :       3.00
TO CONTINUE, ENTER ANY DIGIT AND <CR>0
```

```
          CUMULATIVE WEIGHT %  VS  PASSING SIEVE APERTURE
          -----------------------------------------------

             10     20     30     40     50     60     70     80     90     100
        ------+------+------+------+------+------+------+------+------+------+
 38040. !                                                                    P
 19020. !                                                                   FP
  9510. !                                                                 F  P
  4755. !                                            F                       P
  2378. !                            F                              P        !
  1189. !                  F                       P                         !
   594. !            F                 P                                     !
   297. !        F             P                                             !
   149. !     F           P                                                  !
    74. !    F        P                                                      !
        ------+------+------+------+------+------+------+------+------+------+
             10     20     30     40     50     60     70     80     90     100
TO CONTINUE, ENTER ANY DIGIT AND <CR>0

     STOP
     027400 MAXIMUM EXECUTION FL.
      0.386 CP SECONDS EXECUTION TIME.
```

1.5 REFERENCES

1. *Coal Handbook*, Edited by R.A. Meyers; Marcel Dekker, Inc.; New York and Basel; 1981.

2. Lynch, A.J. *Mineral Crushing and Grinding Circuits; Their Simulation, Optimization, Design and Control*. Elsevier Scientific Publishing Company; 1977.

3. Gupta, V.K. "Identification of rod-mill grinding operation for control under variable ore hardness conditions"; *Proceedings of the 15th International Mineral Processing Congress*, Vol. 3; Cannes; 1985.

2. BALL MILL (BMILL)

2.1 PROGRAM IDENTIFICATION

Program Title:	**B**all **MILL** Model.
Program Code Name:	BMILL.
Authors:	D. Laguitton, F. Flament, from FINDBS code by Robert Spring, Noranda Research Centre Pointe Claire, Quebec.
Organization:	Energy, Mines and Resources Canada, Canada Centre for Mineral and Energy Technology, Mineral Processing Laboratory.
Date:	July 1985.
Updates:	None.
Source Language:	CDC FORTRAN Extended 4.8 (American National Standard Institute FORTRAN X3.9 — 1966).
Availability:	Complete program listing is available from: CANMET, Energy, Mines and Resources Canada, Technology Information Division, 555 Booth Street, Ottawa, Ontario, K1A 0G1.

2.2 ENGINEERING DOCUMENTATION

2.2.1 Narrative Description

A ball-mill is a tumbling mill in which the grinding load consists of a charge of steel-balls cascading as the mill rotates. Mill sizes vary from the small laboratory-scale units (a few centimetres in diameter) to large industrial mills over 10 ft in diameter. Figure 2.1 is an exploded view of a common ball-mill.

In order to simulate accurately the grinding of particles entering a mill, it is necessary to quantify the following concepts:

1. What is the size of the fragments produced by particles of size i as they break?
2. At what rate do particles of size i undergo breakage?
3. For how long are particles of size i submitted to grinding forces?

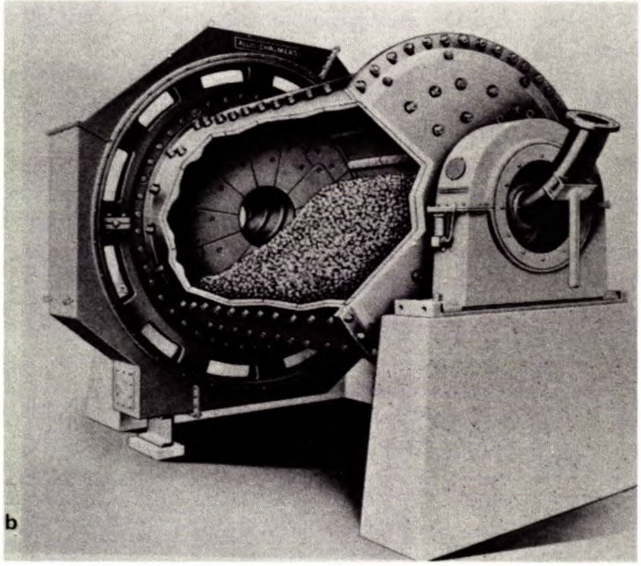

Fig. 2.1 — Exploded view of a ball-mill (Courtesy Allis-Chalmers)

The kinetic model of ball-mills provides an answer to these questions provided some extra assumptions are made which have been proved valid in most instances in the literature, namely:

— Within a mill, the pattern of comminution of a given size interval is constant, i.e., the size distribution of the fragments from a given mother size remains unchanged under normal operating conditions.

— Within a mill, the rate of breakage of a given size interval remains unchanged as long as operating conditions remain constant (e.g., load, ball size, ball load, mill speed, per cent solids).

— The residence time pattern is identical for all size intervals. This latter concept is often extended to assume that there is a perfect identity between the residence time distributions of the solid and the liquid phases.

Based on the above considerations, the kinetic model of ball-mills has remained virtually unchanged for about thirty years and an abundance of references can be found in the literature which deal mostly with improvements in the methods for directly measuring or calculating the model parameters (1,2). In order to shift emphasis towards model applications, only a few basic equations are recalled.

2.2.2 Method of Solution

The following equations and definitions are given without proof:

$$P = GF \qquad \text{Eq 1}$$

where: P = size distribution of product (column vector)
F = size distribution of feed
G = grinding operator (matrix), can be expressed as:

$$G = MEM-1 \qquad \text{Eq 2}$$

where: M_{ij} = 0; for $i < j$
M_{ij} = 1; for $i = j$

$$M_{ij} = \sum_{k=1}^{i-1} \frac{B_{ik}\,S_k}{S_i - S_j} M_{kj};\ \text{for } i > j \qquad \text{Eq 3}$$

E is a diagonal matrix related to the residence time distribution and the grinding kinetics.
B_{ik} is an element of the breakage function matrix B.
S_i is an element of the selection function vector S.

The residence time distribution and functions B and S are discussed in greater detail below.

2.2.2.1 Residence time distribution

Ideally, each particle has its own probability of being discharged at a given time after it enters the mill. In practice the transport of the solids of all size intervals is considered identical to that of the liquid phase. This can be represented by an asymmetrical bell-shaped curve h(t) vs t that satisfies the equation:

$$\int_0^\infty h(t)dt = 1 \qquad \text{Eq 4}$$

The residence time distribution h(t) can in turn be totally defined by a few parameters. As an analogy one can recall the normal distribution curve which is totally defined by its mean and standard deviation. A common model for the ball-mill RTD is the tank in series concept (3) that requires at least three parameters: t_p, t_m and nm. t_p is the plug-flow delay and represents the time at which h(t) departs from zero, nm is the number of perfect mixers that best describes the flow conditions in the mill, and t_m is the mean residence time of the m^{th} mixer. If all mixers are of different sizes, there is one t_m value per mixer. When this model is used, the E_{ii} elements of Equation 2 are given by:

$$E_{ii} = \exp(-t_p S_i) / \prod_{m=1}^{nm} (1 + t_m S_i) \qquad \text{Eq 5}$$

The mean residence time of the mill is then defined as

$$T = t_p + \sum_m t_m \qquad \text{Eq 6}$$

and in the general case by

$$T = \int_0^\infty t\,h(t)dt \qquad \text{Eq 7}$$

Finally, the following relationship is useful for model calibration:

$$H = TW \qquad \text{Eq 8}$$

where W is the mill throughput and H the mill hold-up weight. Other models exist that describe the RTD curve from a small number of parameters (4), and the reader is referred to the abundant literature on the subject (5,6).

2.2.2.2 Breakage function

This parameter, also called breakage distribution, represents the size distribution of fragments from a mother size interval. It is therefore contained in a double entry table generally represented by the letter B. One element B_{ij} of B represents the weight fraction of particles in size interval i that result from breakage of particles in size interval j. All elements of B are null if $i \leq j$ since breakage does not produce particles of a larger size, and it is further assumed that a particle is not broken unless it changes size interval. Matrix B is therefore a lower triangular matrix with a diagonal of zeroes. A further simplification of the model consists in assuming that the value of B_{ij} depends only on the difference $(i-j)$, i.e., for a given ratio of the fragment size to the mother size, the mass of particles is also in a constant ratio. The breakage function is then said to be normalizable or difference similar (7). From the above, it can be seen that the number of breakage function coefficients to be determined varies greatly with the degree of simplification of the model. A full B matrix determination requires $n(n-1)$ values, where n is the number of size intervals considered. A normalized B function requires $n-1$ values. The number of coefficients can be reduced even further if one considers that, as a size distribution of fragments, each column of B can be represented by a function for which regression coefficients can be computed. If the size distribution of the fragments followed a Gaudin-Schuhmann equation (i.e., linear on a log-log scale), each column of B could be represented by two coefficients, a slope and an intercept, and so would a normalized B. In practice, the shape of the size distribution is more complex and up to six coefficients can be required.

Functional forms for B

The following three functional forms have been found to be quite suitable for representing the breakage distribution function for various materials:

$$B_{i,j} = b_1 \left(\frac{x_i}{x_j} \right)^{b_2} + (1 - b_1) \left(\frac{x_i}{x_j} \right)^{b_3} \qquad \text{Eq 9}$$

$$B_{i,j} = b_1 \left(\frac{1.}{x_j} \right)^{b_4} \left(\frac{x_i}{x_j} \right)^{b_2}$$

$$+ (1 - b_1 \left(\frac{1.}{x_j} \right)^{b_4}) \left(\frac{x_i}{x_j} \right)^{b_3} \qquad \text{Eq 10}$$

$$B_{i,j} = b_1 \left(\frac{1.}{x_j} \right)^{b_4} \left(\frac{x_i}{x_j} \right)^{b_2 + b_5 \ln(x_j)/\ln(R)}$$

$$+ (1 - b_1 \left(\frac{1.}{x_j} \right)^{b_4}) \left(\frac{x_i}{x_j} \right)^{b_3 + b_6 \ln(x_j)/\ln(R)} \qquad \text{Eq 11}$$

where b_1, b_2, b_3...b_6 are constants, x_i is the size of interval i in millimetres, and R is the sieve size ratio. We suggest x_i be the geometric mean size of the interval, although it could also be the upper or lower limit of each size interval or the arithmetic mean size. Consistency in this matter is essential. Equation 9 generates a difference-similar set of breakage distribution parameters. For small deviations from the difference-similar form, Equation 9 is good. For larger deviations from the difference-similar form, Equation 11 should be used.

2.2.2.3 Selection function

This parameter is also referred to as the breakage rate parameter, represented by S_i for size interval i. It is a vector with dimension time^{-1}. The interdependence of S_i and B_{ij} has always been a source of complication in ball-mill modelling. It can indeed be understood intuitively that whatever the true changes inside the mill, an increase in the amount of material in a given size interval i can always be interpreted as resulting from an increase in B_{ij}, or an increase in S_j, or a decrease in S_i. In other words, more fragments from upper sizes may have been produced by breakage at the same rate, or the rate of breakage of upper size intervals may have increased while the size distribution of the fragments remained unchanged, or the rate of breakage of the considered size interval may have declined. A combination of all the above may also be the case. But in practice it has been shown that S depends mostly on the mill variables, while B is mostly ore related and can be estimated in laboratory experiments (8). This decoupling of the B and S function opens the possibility of simulating the grinding of new ores for which industrial data are not available.

Another remark of importance must be made about the S function: multiplying S_i by any constant does not change the value of M_{ij} in Equation 3. In continuous grinding, the mean residence time is often unknown for some of the conditions under which samples were collected. It is therefore convenient to replace S_i by S_iH and T by 1/W, where the hold-up weight H and the flow rate W are related by Equation 8. The product S_iH is calculated instead of the true S_i. Depending on the authors, one can find as values for S the *true* rate constants or a scaled selection function ST or SH, multiplied by the mean residence time or by the mill hold-up weight. The dimension of S_i varies accordingly from time^{-1} to dimensionless, or to mass per unit of time.

Functional forms for S

The following two functional forms have been found to be quite suitable for the rate function:

$$S_i = \frac{s_1 x_i^{s_2}}{1 + s_3 x_i^{s_4}} \qquad \text{Eq 12}$$

$$\ln S = \ln s_1 + s_2(\ln x_i) + s_3(\ln x_i)^2 + s_4(\ln x_i)^3 + \ldots \qquad \text{Eq 13}$$

where s_1, s_2, s_3, etc. are constants. The functional form in Equation 13 is the most flexible one.

Depending on the complexity of the shape of the rate function curve, higher order terms can be included in the polynomial. The functional form (Eq 13) is implemented in the program up to the third degree, but it could be easily extended to higher degrees, if needed.

2.3 PROGRAM AND SUBROUTINES

2.3.1 Program XBMILL

2.3.1.1 Purpose

Driver for the kinetic ball mill model.

2.3.1.2 Usage

Execute as main program.

2.3.1.3 Variables to be read

NS = number of size fractions (pan included).
NG = number of specific gravity fractions.
NC = number of characteristics.
FEEDS = mass flow rate of solids in feed (tonnes/h).
FEEDW = mass flow rate of water in feed (tonnes/h).
FEED = three-dimensional array containing the solids characteristics 'assays' for the feed stream (resides on a disk file as follows: NC sets of NS records, each record having NG values) (cum. pass. weight fraction.).

The program for the model BMILL permits two modes of data entry. In the first, coefficients of the equations to calculate the breakage and selection functions are entered. In the second, the elements of the breakage and selection matrices are entered directly.

To calculate the breakage and selection functions, the parameter vector is defined as follows:

PARAM = parameter vector — 1 to NCB = vector of NCB coefficients for breakage function calculation (using the 3-, 4-, or 6-coefficient equations given in Chapter 5.2).
(NCB+1) to (NCB+NCS) = vector of NCS coefficients for selection function calculation (using the 2-, 3-, 4-, or 5-coefficient equations given in Chapter 5.2).
(NCB+NCS+1) to (NCB+NCS+NM) = vector of values of the fraction of total average retention time for NM mixers.
NCB+NCS+NM+1 = reference particle size used to calculate breakage and selection functions (mm).

To enter values of breakage and selection function directly, set NCB and NCS = 1. In this case, the parameter vector is defined as follows:

PARAM = parameter vector — 1 to NS*NS = breakage function matrix (size = NS*NS).
(NS*NS+1) to NS*(NS+1) = selection function vector (size = NS).
(NS*NS + NS + 1) to NS*(NS+1)+NM = vector of values of the fraction of total average residence time for NM mixers.

OPT = option vector — 1 = NCB
2 = NCS
3 = NM.
NCB = number of coefficients to calculate breakage function.
NCS = number of coefficients to calculate selection function.
NM = number of mixers.
XMU = vector of upper sizes for the intervals (micrometres).
SG = vector of upper specific gravities for intervals.

2.3.1.4 Subroutines and functions required

RDFILE, UDRIVR, SETPAR, BMOUT.

2.3.2 Subroutine SETPAR

2.3.2.1 Purpose

To decode the combined OPT (1) vector before calling subroutines BREAK and SELECT.

To set up the PARAM vector depending on the mode of the data entry.

To set up a size vector (in millimetres) from which to calculate breakage and selection functions.

2.3.2.2 Usage

CALL SETPAR (PARAM, OPT, NS).

2.3.2.3 Parameters list

Refer to Section 2.3.1.3.

2.3.2.4 Subroutines and functions required

BREAK, SELECT.

2.3.3 Subroutine BREAK

2.3.3.1 Purpose

Calculate the breakage function matrix.

2.3.3.2 Usage

CALL BREAK (X, N, OPT).

2.3.3.3 Description of variables

N = number of screen NS.
OPT = number of parameters.
X = vector of breakage function parameters.

2.3.4 Subroutine SELECT

2.3.4.1 Purpose

To calculate the selection function matrix.

2.3.4.2 Usage

CALL SELECT (X, N, OPT).

2.3.4.3 Description of variables

N = number of screen sizes.
OPT = number of parameters.
X = parameter vector.

2.3.5 Subroutine BMILL

2.3.5.1 Purpose

This program directs the execution of subroutines which collectively predict the product size distribution(s) for the given feed size distribution(s).

2.3.5.2 Usage

CALL BMILL (NS, NG, NC, FEEDS, FEEDW, FEED, PRODS, PRODW, PROD, SOL3, WAT3, CH3, SOL4, WAT4, CH4, DER1, DER2, DER3, PARAM, OPT).

2.3.5.3 Description of variables

B = breakage function matrix.
FMIX = fraction of total average residence time due to mixer.
G = grinding matrix = Z*V*ZINV.
MIXERS = number of perfect mixers.
NS = number of screen sizes.
PROD = predicted size distributions.
R = screen size ratio = size(I)/next larger size.
S = selection function vector.
V = vector used with Z matrix.
PARAM = parameter vector — 1 to NS*NS = B
(NS*NS+1) to (NS*NS+NS) = S
(NS*NS+NS+1) to
(NS*NS+NS+MIXERS) = FMIX
(NS*NS+NS+MIXERS + 1) =
Reference particle size used in FINDBS.
Z = diagonalized grinding matrix.

2.3.5.4 Subroutines and functions required

MAKEV = calculates the mixers function V.
MAKEZ = calculates the diagonalized grinding matrix.
MAKEG = calculates grinding matrix G.
GRIND = calculates predicted size distributions.

2.3.6 Subroutine MAKEV

2.3.6.1 Purpose

To calculate the mixers function V.

2.3.6.2 Usage

CALL MAKEV (S, V, NS, T, FMIX, MIXERS).

2.3.6.3 Description of variables

FMIX = fraction of total residence time due to mixer.
MIXERS = number of perfect mixers.
NS = number of screen sizes.
S = selection function.
T = total residence time.
V = mixers function.

2.3.7 Subroutine MAKEZ

2.3.7.1 Purpose

The diagonalized grinding matrix Z is calculated from the breakage and selection functions. The inverse of Z is also calculated.

2.3.7.2 Usage

CALL MAKEZ (B, S, NS, Z).

2.3.7.3 Description of variables

B = breakage function matrix.
NS = number of screen sizes.
S = selection function vector.
Z = diagonalized grinding matrix.

2.3.8 Subroutine MAKEG

2.3.8.1 Purpose

The product G=Z*V*ZINVERSE is calculated.

2.3.8.2 Usage

CALL MAKEG (Z, V, NS, G).

2.3.8.3 Description of variables

G = grinding matrix = Z*V*ZINVERSE.
NS = number of screen sizes.
V = vector used with Z matrix.
Z = diagonalized grinding matrix.

2.3.9 Subroutine GRIND

2.3.9.1 Purpose

The grinding matrix G is used to calculate the product size distribution.

2.3.9.2 Usage

CALL GRIND (G, NS, FEED, PROD).

2.3.9.3 Description of variables

FEED = feed size distribution.
G = grinding matrix = Z*V*ZINV.
NS = number of screen sizes.
PROD = product size distribution.

2.3.10 Subroutine BMOUT

2.3.10.1 Purpose

Subroutine BMOUT gives a graphical representation of a ball mill.

It presents, in table and graph form, the size distributions of the feed and discharge streams.

2.3.10.2 Usage

CALL BMOUT (NS, NG, NC, FEEDS, FEEDW, FEED, PRODS, PRODW, PROD, SOL3, WAT3, CH3, SOL4, WAT4, CH4, DER1, DER2, DER3, PARAM, OPT).

2.3.10.3 Parameters list

See Sections 2.3.1 and 2.3.5.

2.3.10.4 Subroutines and functions required

PLOTSZ.

2.3.11 Other Subroutines

Details of subroutines RDFILE, UDRIVR and PLOTSZ (and its subroutine INITGR) are given in Chapters 5 and 5.1 of the SPOC Manual.

2.4 SAMPLE RUN

The program is demonstrated below for a batch-mill simulation and a continuous-grinding experiment.

2.5 REFERENCES

1. Luckie, P.T., and Austin, L.G. "A review introduction to the solution of the grinding equations by digital computation"; *Miner Sci Eng* 4:2:24-51; April 1972.

2. Klimpel, R.R., and Austin, L.G. "The Back-Calculation of Specific Rates of Breakage and Non-Normalized Breakage Distribution Parameters from Batch Grinding Data"; *Int J Miner Process* 4:7-32; 1977.

3. Levenspiel, O. *Chemical Reaction Engineering*, Chapter 9, "Non Ideal Flow"; John Wiley; 1962.

4. Himmelblau, D.M., and Bischoff, K.B. *Process Analysis and Simulation*, Section 4-6; John Wiley; 1968.

5. Gardner, R.P.; Aissa, M.; and Verghese, K. "Determination of ball-mill residence time distribution from tracer data taken in closed circuit operation"; *Powder Technology* 32:253-266; 1982.

6. Abouzeid, A.; Mika, T.; Sastry, K.; and Fuerstenau, D.W. "The influence of operating variables on the residence distribution for material transport in a continuous rotary drum"; *Powder Technology* 10:273-288; 1974.

7. Herbst, J.A., and Fuerstenau, D.W. "The zero order production of fine sizes in comminution and its implications in simulation"; *Trans Soc Min Eng* 241:4:538-548; 1968.

8. Kelsall, D.F.; Reid, K.J.; and Restarick, C.J. "Continuous grinding in a small wet ball-mill, Part 1, Study of the Influence of Ball Diameter"; *Powder Technology* 1:221-300; 1967-68.

BALL MILL MODEL (BMILL)

PROGRAM DESCRIPTION: THIS IS THE KINETIC MODEL OF BALL-MILLING WHICH SIMULATES THE GRINDING OF PARTICLES BY QUANTIFYING THE SIZE DISTRIBUTION OF THE GROUND PRODUCT, THE RATE OF BREAKAGE AND THE RESIDENCE TIME OF PARTICLES IN THE MILL. THIS IS DONE BY ASSUMING:

(1) THAT THE PATTERN OF COMMINUTION OF A GIVEN SIZE INTERVAL IS CONSTANT UNDER NORMAL OPERATING CONDITIONS,
(2) THAT THE RATE OF BREAKAGE REMAINS CONSTANT AS LONG AS OPERATING CONDITIONS REMAIN UNCHANGED,AND
(3) THAT THE RESIDENCE TIME IS IDENTICAL FOR ALL SIZE INTERVALS.

THE PROGRAMS AND SUBROUTINES ARE:

XBMILL,RDFILE,UDRIVR,SETPAR,BREAK,SELECT,BMILL,GRIND,
MAKEG,MAKEV,MAKEZ,BMOUT,PLOTSZ,INITGR

THE VARIABLES REQUIRED ARE AS FOLLOWS:

```
NS      = NUMBER OF SIZE FRACTIONS (PAN INCLUDED)
NG      = NUMBER OF SPECIFIC GRAVITY FRACTIONS = 1
NC      = NUMBER OF CHARACTERISTICS = 1
SOL     = FEEDS = MASS FLOW RATE OF SOLIDS IN FEED (TONNES/HR)
WAT     = FEEDW = MASS FLOW RATE OF WATER IN FEED (TONNES/HR)
FEED    = 3-DIMENSIONAL ARRAY CONTAINING THE SOLIDS
          CHARACTERISTICS "ASSAYS" FOR THE FEED STREAM
          (RESIDES ON A DISK FILE AS FOLLOWS:  NC(=1) SETS
           OF NS RECORDS, EACH RECORD HAVING NG(=1) VALUES)
          (WT. PERCENT RETAINED)
```

THE PROGRAM FOR THE MODEL 'BMILL' PERMITS TWO MODES OF DATA ENTRY. IN THE FIRST, COEFFICIENTS OF THE EQUATIONS TO CALCULATE THE BREAKAGE AND SELECTION FUNCTIONS ARE ENTERED. IN THE SECOND, THE ELEMENTS OF THE BREAKAGE AND SELECTION MATRICES ARE ENTERED DIRECTLY.

1) TO CALCULATE THE BREAKAGE AND SELECTION FUNCTIONS, THE PARAMETER VECTOR IS DEFINED AS FOLLOWS:(NOTE THAT THE LAST ELEMENT OF THE PARAM VECTOR IS THE REFERENCE PARTICLE SIZE IN MILLIMETRES USED IN THE BREAKAGE AND SELECTION FUNCTION EQUATIONS. IT IS THE UPPER SIZE OF COARSEST FRACTION IN THE FEED)

```
PARAM  = PARAMETER VECTOR - 1 TO NCB = VECTOR OF NCB COEFFICIENTS
                                       FOR BREAKAGE FUNCTION
                                       CALCULATION (USING THE 3-,
                                       4- OR 6-COEFFICIENT EQUATIONS
                                       GIVEN IN CHAPT. 5.2)
                 (NCB+1) TO (NCB+NCS) = VECTOR OF NCS COEFFICENTS
                                       FOR SELECTION FUNCTION
                                       CALCULATION (USING THE 2-,3-,
                                       4-COEFFICIENT EQUATIONS
                                       GIVEN IN CHAPT. 5.2)
```

```
            (NCB+NCS+1) TO (NCB+NCS+NM) = VECTOR OF VALUES OF
                                          THE FRACTIONS OF TOTAL AVERAGE
                                          RETENTION TIME FOR NM MIXERS
                                          (IF NM=0, PARAM(NCB+NCS+1) IS THE
                                           BATCH MILL GRINDING TIME)
                            NCB+NCS+NM+1 = REFERENCE PARTICLE SIZE USED
                                          TO CALCULATE BREAKAGE AND
                                          SELECTION FUNCTIONS(MM)

     2) TO ENTER VALUES OF BREAKAGE AND SELECTION FUNCTION DIRECTLY, SET
     NCB AND NCS = 1. IN THIS CASE, THE PARAMETER VECTOR IS DEFINED AS
     FOLLOWS:

    PARAM = PARAMETER VECTOR - 1 TO NS*NS = BREAKAGE FUNCTION MATRIX
                                           (SIZE = NS*NS)
                 (NS*NS+1) TO NS*(NS+1) = SELECTION FUNCTION VECTOR
                                           (SIZE = NS)
           (NS*NS +NS+1) TO NS*(NS+1)+NM = VECTOR OF VALUES OF THE
                                          FRACTION OF TOTAL AVERAGE
                                          RESIDENCE TIME FOR NM MIXERS

     OPT    = OPTION VECTOR             - 1 = NCB
                                          2 = NCS
                                          3 = NM
     NCB    = NUMBER OF COEFFICIENTS TO CALCULATE BREAKAGE FUNCTION
     NCS    = NUMBER OF COEFFICIENTS TO CALCULATE SELECTION FUNCTION
     NM     = NUMBER OF MIXERS (IF 0, MILL IS SUPPOSED TO BE A BATCH MILL)

     XMU    = VECTOR OF UPPER SIZES FOR THE INTERVALS (MICROMETRES)
     SG     = VECTOR OF UPPER SPECIFIC GRAVITIES FOR
              INTERVALS



           DATA ENTRY FOR : BMILL(BATCH)


 THE DEFAULT VALUES OF NS,NG,NC,SOL & WAT ARE:

12 1 1 100. 0.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
62.96 36.72 .16 0. 0. 0. 0. 0. 0. 0. 0. .16
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
.3984 .9199 20.23 .1374 .2603 .3145 .006862 .09395 4. 2.022
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE OPTIONS  RELATED TO THIS SIMULATOR ARE:
4. 4.
 CHANGE?(Y/N)
n
```

```
 THE DEFAULT VALUES FOR THE ARRAY OF SIZES ARE:

2022. 1430. 1011. 715. 506. 358. 253. 179. 126.5 89.5 63.3 44.8
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SPECIFIC GRAVITIES ARE:
4.5
 CHANGE?(Y/N)
n

   BATCH BALL MILL WITH A RT =   4.0000
TO CONTINUE, ENTER ANY DIGIT AND <CR>0
```

BALL MILL UNIT

SCREENS	FEED %CUM	FEED %RET	PRODUCT %CUM	PRODUCT %RET
2022.- 1430.	100.000	62.960	100.000	16.368
1430.- 1011.	37.040	36.720	83.632	29.136
1011.- 715.	.320	.160	54.496	20.287
715.- 506.	.160	0.000	34.209	10.422
506.- 358.	.160	0.000	23.787	6.065
358.- 253.	.160	0.000	17.722	4.324
253.- 179.	.160	0.000	13.398	3.322
179.- 127.	.160	0.000	10.076	2.564
127.- 90.	.160	0.000	7.511	1.951
90.- 63.	.160	0.000	5.560	1.458
63.- 45.	.160	0.000	4.102	1.074
45.- 0.	.160	.160	3.028	3.028

```
TO CONTINUE, ENTER ANY DIGIT AND <CR>0

          CUMULATIVE WEIGHT %  VS  PASSING SIEVE APERTURE
          -----------------------------------------------

              10     20     30     40     50     60     70     80     90    100
        ------+------+------+------+------+------+------+------+------+------+
  2022. !                                                                    P
  1430. !                        F                               P           !
  1011. F                                    P                               !
   715. F                      P                                             !
   506. F               P                                                    !
   358. F          P                                                         !
   253. F       P                                                            !
   179. F     P                                                              !
   127. F   P                                                                !
    90. F  P                                                                 !
    63. F P                                                                  !
    45. FP                                                                   !
        ------+------+------+------+------+------+------+------+------+------+
              10     20     30     40     50     60     70     80     90    100
TO CONTINUE, ENTER ANY DIGIT AND <CR>0

NORMAL PROGRAM TERMINATION
     STOP  0
     030700 MAXIMUM EXECUTION FL.
      0.436 CP SECONDS EXECUTION TIME.
```

```
               DATA ENTRY FOR : BMILL(CONTIN)

 THE DEFAULT VALUES OF NS,NG,NC,SOL & WAT ARE:

15 1 1 847.5 0.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
.55 1.06 2.53 3.84 6.71 9.57 11.16 12.66 14.95 11.08 6.23 4.29
3.17 1.63 10.57
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
.3984 .9199 20.23 .1374 1014. .6541 -.2261 -.1295 .5293 .1593
.0779 5.718
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE OPTIONS  RELATED TO THIS SIMULATOR ARE:
4. 4. 3.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SIZES ARE:

5718. 4044. 2860. 2022. 1430. 1011. 715. 506. 358. 253. 179.
127. 90. 63. 45.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SPECIFIC GRAVITIES ARE:
4.5
 CHANGE?(Y/N)
n



                                   ___
                                  !   !__________________
                                  !   !                  !
                                  !   !    BALL MILL     !
        SFR=  847.50            --!   !                  !--  SFR=  847.50
        WFR=    0.00              !   !                  !    WFR=    0.00
         %S=  100.00            --!   !    3 MIXERS      !--   %S=  100.00
                                  !   !                  !
                                  !   !__________________!
                                  !___!
TO CONTINUE, ENTER ANY DIGIT AND <CR>0
```

BALL MILL UNIT

SCREENS	FEED %CUM	FEED %RET	PRODUCT %CUM	PRODUCT %RET
5718.- 4044.	100.000	.550	100.000	.238
4044.- 2860.	99.450	1.060	99.762	.451
2860.- 2022.	98.390	2.530	99.311	.956
2022.- 1430.	95.860	3.840	98.355	1.734
1430.- 1011.	92.020	6.710	96.620	3.346
1011.- 715.	85.310	9.570	93.274	5.975
715.- 506.	75.740	11.160	87.299	8.908
506.- 358.	64.580	12.660	78.391	11.641
358.- 253.	51.920	14.950	66.750	14.426
253.- 179.	36.970	11.080	52.323	12.950
179.- 127.	25.890	6.230	39.374	8.899
127.- 90.	19.660	4.290	30.474	6.278
90.- 63.	15.370	3.170	24.196	4.605
63.- 45.	12.200	1.630	19.590	2.874
45.- 0.	10.570	10.570	16.716	16.716

3 MIXERS INCLUDING PLUG FLOW OF : .23
MIXERS RT'S ARE : .5293 .1593 .0779
TO CONTINUE, ENTER ANY DIGIT AND <CR>0

CUMULATIVE WEIGHT % VS PASSING SIEVE APERTURE

```
            10     20     30     40     50     60     70     80     90    100
      ------+------+------+------+------+------+------+------+------+------+
5718. !                                                                    P
4044. !                                                                    P
2860. !                                                                   P!
2022. !                                                                 F P!
1430. !                                                              F   P !
1011. !                                                          F    P    !
 715. !                                                   F       P        !
 506. !                                           F         P              !
 358. !                                  F          P                      !
 253. !                        F          P                                !
 179. !                F         P                                         !
 127. !            F      P                                                !
  90. !         F     P                                                    !
  63. !      F     P                                                       !
  45. !     F    P                                                         !
      ------+------+------+------+------+------+------+------+------+------+
            10     20     30     40     50     60     70     80     90    100
```

TO CONTINUE, ENTER ANY DIGIT AND <CR>0

NORMAL PROGRAM TERMINATION
STOP 0
030700 MAXIMUM EXECUTION FL.
0.521 CP SECONDS EXECUTION TIME.

3. MOGENSEN SIZER (MOGENS)

3.1 PROGRAM IDENTIFICATION

Program Title: **MOGEN**sen **S**izer Model.

Program Code Name: MOGENS.

Authors: J.M. Beeckmans, R.F. Pilgrim.

Organization: Energy, Mines and Resources Canada, Canada Centre for Mineral and Energy Technology, Mineral Processing Laboratory.

Date: March 1984.

Updates: June 1985. Modifications to permit uniform parameter list in calling unit simulator subroutines.

Source Language: CDC FORTRAN Extended 4.8 (American National Standard Institute FORTRAN X3.9 — 1966).

Availability: Complete program listing is available from:
CANMET,
Energy, Mines and Resources Canada,
Technology Information Division,
555 Booth Street,
Ottawa, Ontario,
K1A 0G1.

3.2 ENGINEERING DOCUMENTATION

3.2.1 Narrative Description

A linear, multi-deck probability screening machine differs from a conventional screening machine principally in the steeper angle of inclination of the screen, and in the direction, amplitude, and frequency of the vibrations. Typically, a probability screen operates at an angle of 18 degrees or greater to the horizontal, and is vibrated in a direction which is predominantly normal to the plane of the screen, at a frequency in the range 15-30 Hz, and with an amplitude of 2-5 mm. (The screen angles in the Mogensen Sizer are 18°, 24°, 30°, 32.5° and 34°.) Conventional screening machines are vibrated in a direction predominantly parallel to the material flow vector, with amplitudes frequently ranging to 50 mm, at frequencies which are generally much lower than those used in probability screens.

The first probability screening machine was patented by Mogensen in 1951 (1), and subsequent patents were issued in 1958, 1966 and 1973 (2-4). The machine is presently manufactured in Europe and in North America (Royer-Mogensen Inc., Kingston, Pa.) (Fig. 3.1).

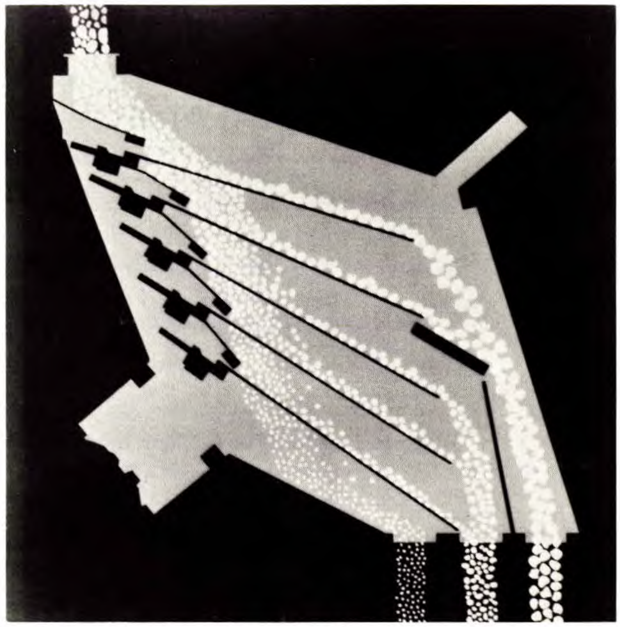

Fig. 3.1 — Cutaway view of a Mogensen sizer (Courtesy of Royer/Mogensen, Inc.)

The theoretical objective in conventional screening is to separate particles smaller than the screen aperture size from those which are larger. Although this objective can never be fully realized in practice, the machine is designed to approach this ideal as closely as possible.

The objective in a probability screening machine is to separate the feed into coarse and fine fractions as economically as possible. The screen aperture size does not denote the point of separation between the fine and coarse fractions, since in general the overflow will contain a significant proportion of particles whose size is smaller than the screen aperture size. Probability screening machines sacrifice a degree of screening accuracy in favour of a significantly higher throughput per unit area, and reduced tendency to blinding.

The Mogensen Sizer can accomodate five screens, and is manufactured in widths of 0.5, 1.0, 1.5, and 2 metres. Overflow streams are frequently partially combined so as to yield less than the maximum number of products. Better separation and less blinding can usually be achieved by combining overflows from two or more screens than by using a single screen.

The SPOC routine MOGENS simulates operation of a probability screening machine known as the Mogensen Sizer (MS). It uses empirical correlations based on data obtained with coal and sand-gravel mixtures at the Coal Mining Research Centre in Edmonton. Because of their complexity, no attempt is made to model the phenomena occurring in the MS.

The methodology used for interpreting the data, deriving the correlations, and applying them to a multideck MS has been described by Beeckmans et al. (5), and only a brief overview is given here.

3.2.2 Mathematical Derivation

The propensity of particles of different sizes to penetrate a given screen is characterized using a specific penetration function B(x), which is defined on the basis that the probability that a particle of size x will penetrate a differential element of screen of length dz and unit width equals B(x)dz. If B(x) is constant over the length of the screen, the partition function is given by the equation

$$P(x) = \exp[-B(x)L] \qquad \text{Eq 1}$$

where L equals the length of the screen.

The correlations permit values of B(x) to be estimated at particular points, known as characteristic points, for a single screen. The characteristic points correspond to values of P(x) equal to 0.1, 0.25, 0.5, and 0.75 on a screen of effective length 1.15 metres. One additional characteristic point is defined, the point at which $B(x) = 0.1\ m^{-1}$. The variables which enter the correlations are the feed rate, the mean specific gravity of the feed, the frequency and amplitude of vibration of the screens, and their aperture, angle of inclination, and length. The correlation equations are:

$$x_{0.10} = [0.994 - 0.00814(f\theta) - 0.00236(A\theta) + 0.0108\,(F_r x_A) - 0.000485\,x_A^2 - 0.0223\,\rho]x_A \qquad \text{Eq 2}$$

$$x_{0.25} = [0.945 - 0.00668(F\theta) - 0.562 \times 10^{-5}\theta^3 + 0.00943\,(F_r x_A) - 0.00204\,(Ax_A) - 0.0250\rho]x_A \qquad \text{Eq 3}$$

$$x_{0.50} = [1.074 - 0.00795(f\theta) + 0.00358\,(F_r x_A) - 0.0312\rho + 0.0169(fF_r) - 1.638\,\eta(\theta)]x_A \qquad \text{Eq 4}$$

$$x_{0.75} = [1.2481 - 0.00453(f\theta) + 0.0547(fF_r) - 0.00275(A\theta) - 0.0132\,F_r^2 - 0.0536\,f^2]x_A \qquad \text{Eq 5}$$

$$x_{0.882} = [1.322 - 0.00219(f\theta) + 0.0327(fF_r) - 4.36\,\eta(\theta) - 0.0257(fA) - 0.0238\,f^2]x_A \qquad \text{Eq 6}$$

The symbols are defined as follows:

- A = amplitude of vibration (mm).
- F = feed rate (tonnes/h).
- F_r = feed rate function: $F_r = (F/x_A \rho W)^{0.5}$.
- f = frequency of vibration (cycles/minute).
- x_A = aperture size (mm).
- $x_{0.1}$ = particle size for which P(x) equals 0.1 (analogous definitions for $x_{0.25}$, $x_{0.5}$, $x_{0.75}$, and x0.882. The last corresponds to $B = 0.1\ m^{-1}$).
- W = Screen width (m).
- θ = angle of inclination of the screen (degrees).
- ρ = mean specific gravity of the feed.
- $\eta(\theta)$ = empirical function: $\eta(\theta) = (42.0 - \theta)^{-1}$.

The coordinates of the characteristic points are evaluated for each screen, and a second-order polynomial is fitted to them by least-squares. The polynomial curve is a representation of the *characteristic function*, $\ell n(B(x))$. The present procedure differs from that described by Beeckmans et al. (5) in that previously the characteristic function was obtained by fitting a fourth-order polynomial to the characteristic points. In some cases positive slopes were found over certain regions of the curve, in which case a second-order polynomial was fitted by least-squares. Since execution time is a significant consideration in running the program in the context of a plant simulation, which may contain recycle streams, the simpler procedure is used in this case.

Flow through and over screens, other than the top screens, is calculated by integrating the following set of equations:

For j = 2 to j = k (k equals the number of screens)

$$d(\Delta M_j(z,x)) = -\,\Delta M_j(z,x)B_j(x)dz + \Delta M_{j-1}(z,x)B_{j-1}(x)dz \qquad \text{Eq 7}$$

subject to boundary conditions

$$\Delta M_j(0,x) = 0 \qquad j \neq 1 \qquad \text{Eq 8}$$

$$\Delta M_1(0,x) = Ff(x)dx$$

$\Delta M_j(z,x)$ equals the rate of flow of particles with sizes in the interval (x_i, x_{i+1}), above screen j at a distance z from the feed point; F equals the feed rate and f(x) is the size distribution function of the feed. The overflow flowrate over screen j is

$$O_j = \int_0^{\infty} \Delta M_j(L,x)dx \qquad \text{Eq 9}$$

Flow over the top screen was computed by an equation analogous to Equation 7, but with the second term on the right of the equal sign deleted.

Equation 7 implies that material penetrating screen j, at a distance z along that screen from its leading edge, lands on the next screen at a point which is at the same distance z from the beginning of that screen, as measured along its surface. This assumption is obviously only approximately true, since the screens are to some extent offset (i.e., their leading edges do not lie in a vertical plane) and they are inclined at differing angles, and also because the material which penetrates a screen at a particular point would be expected to land over a finite area of the screen below, rather than at a fixed distance from its leading edge. Finally, the flowrate of underflow through the bottom screen is found from the equation

$$U = F - \sum_{j=1}^{k} O_j \qquad \text{Eq 10}$$

The uniformity assumption is used in evaluating f(x) within each size interval. Each size interval is further subdivided into a number of subintervals (the number of subintervals is specified by the user), and the value of B(x) is computed using the mean value of x in the subinterval. Thus for every size-interval, the proportion appearing in the overflows from each of the screens, and in the underflow to the bottom screen, is calculated. The distribution of water among the overflows to the various screens is specified by the user. The amount of water in the underflow is then calculated by difference.

The mean specific gravity of the feed was computed as follows:

$$\sigma = 100/(\Sigma w_i/\bar{\sigma}_i)$$

where w_i equals the percentage of material in the feed (all sizes) in the specific gravity interval i, and $\bar{\sigma}_i$ equals the mean specific gravity in interval i.

3.2.3 Limitations

Because of the empirical nature of the correlations, it is recommended that all of the independent variables should be maintained within the ranges studied in developing the correlation equations.

Recommended Ranges for the Independent Variables

Aperture size:	850-13 000 micrometres
Angle of inclination of screen to the horizontal:	18-34 degrees
Feed rate:	0-50 tonnes/mh (per meter of screen width)
Specific gravity of feed:	1.3-2.65
Frequency of vibration:	0.9-1.8 khz
Amplitude of vibration:	3-4 mm

3.3 PROGRAM AND SUBROUTINES

3.3.1 Program XMOGENS

3.3.1.1 Purpose

To read default data from unit 5 and modify data as required using subroutines RDFILE and UDRIVR; to execute the subroutines MOGENS, MG2OUT, MGNOUT, and DETOUT.

3.3.1.2 Usage

Execute as a main program.

3.3.1.3 Variables to be read

NS = number of size intervals.
NG = number of specific gravity intervals.
NC = number of characteristics.
FEEDS = mass flow rate of solids in feed (tonnes/h).
FEEDW = mass flow rate of water in feed (tonnes/h).
FEED = three-dimensional array containing the solids characteristic 'assays' for the feed stream.
PARAM = parameter vector
1: FREQ
2: AMPL
3: W.
4 to (NSCR+3): ANGLE
(4+NSCR) to (2*NSCR+3): APER
(2*NSCR+4) to (3*NSCR+3): WATOF
(3*NSCR+4) to (3*NSCR+8): FS
(3*NSCR+9) to (3*NSCR+13): EL.
FREQ = frequency of vibration (cycles/min).
AMPL = amplitude of vibration (mm).
W = screen width (m).
ANGLE = vector of screen inclinations (degrees).
APER = vector of screen apertures (micrometres).
WATOF = vector of per cent water in each of the overflow streams.
FS = vector of screen loadings (tonnes/h).
EL = vector of screen lengths (m).
OPT = option vector
1: FLAG
2: MODE
3: RCYC
4: NI
5: NSCR.
FLAG = flag to request detailed output of product streams
0: summary output
1: summary plus detailed output.
MODE = flag to request combined overflows
0: overflows not combined
1: overflows combined.
RCYC = flag to request recomputation of characteristic points after individual screen flows have been calculated on the first pass
0: no recalculation performed
1: characteristic curve recalculated.
NI = number of integration intervals per size interval.
NSCR = number of screens used (max = 5).
XMU = vector of upper sizes for the size intervals (micrometres).
SG = vector of upper specific gravities for the specific gravity intervals.

Note: For details of subroutines RDFILE, UDRIVR, and DETOUT, see Chapters 5 and 5.1 of the SPOC Manual.

3.3.2 Subroutine MOGENS

3.3.2.1 Purpose

To simulate the performance of the Mogensen Sizer.

3.3.2.2 Usage

CALL MOGENS (NS, NG, NC, FEEDS, FEEDW, FEED, SOL2, WAT2, CH2, SOL3, WAT3, CH3, SOL4, WAT4, CH4, DER1, DER2, DER3, PARAM, OPT).

3.3.2.3 Parameters list

NS, NG, NC, FEEDS, FEEDW, FEED, PARAM, OPT } are defined in Section 3.3.1.3.

SOLi = solids flow rate (tonnes/h) for i from 2 to 4 (unused in this model).
WATi = water flow rate (tonnes/h) for i from 2 to 4 (unused in this model).
CHi = three-dimensional array of characteristic 'assays' for i from 2 to 4 (unused in this model).
DERi = derivative vector for i from 1 to 3 (unused in this model).

3.3.3 Subroutine MG2OUT

3.3.3.1 Purpose

To output data generated by the Mogensen Sizer using a single combined overflow stream.

3.3.3.2 Usage

CALL MG2OUT (NS, NG, NC, FEEDS, FEEDW, PRODS, PRODW, COARSE, FINE, PARAM, OPT).

3.3.3.3 Parameters list

NS, NG, NC, FEEDS, FEEDW, PARAM, OPT } are defined in Section 3.3.1.3.

PRODS = vector of mass flows of solids from the combined overflows and from the underflow from the last screen (tonnes/h).
PRODW = vector of mass flows of water from the various screens and from the underflow from the last screen (tonnes/h).
COARSE = three-dimensional array of characteristic 'assays' for the underflow stream.
FINE = three-dimensional array of characteristic 'assays' for the combined overflow streams.

3.3.4 Subroutine MGNOUT

3.3.4.1 Purpose

To output data generated by the Mogensen Sizer — a probability screen model.

3.3.4.2 Usage

CALL MGNOUT (NS, NG, NC, FEEDS, FEEDW, FEED, PRODS, PRODW, OUT1, OUT2, OUT3, OUT4, OUT5, OUT6, PARAM, OPT).

3.3.4.3 Parameters list

NS, NG, NC, FEEDS, FEEDW, FEED, PARAM, OPT } are defined in Section 3.3.1.3.

PRODS, PRODW are defined in Section 3.3.3.3.
OUTi = three-dimensional array containing the characteristic 'assays' of the overflow stream from the ith screen. If i = NSCR + 1, the array contains the characteristic assays of the underflow stream.

3.4 SAMPLE RUN

A typical sample run is presented in the following pages, using input data from Table 1.

3.5 REFERENCES

1. Mogensen, F.K. US 2,572,177; October 23, 1951.
2. Mogensen, F.K. US 2,853,191; September 23, 1958.
3. Mogensen, F.K. US 3,254,765; June 7, 1966.
4. Mogensen, N.P. US 3,710,940; January 16, 1973.
5. Beeckmans, J.M.; Hu, E.; Germain, R.; and McIntyre, A. "Performance characteristics of a probability screening machine"; *Powder Technology* 43:249-256; 1985.

Table 1 – Data for MOGENS

Unit: Mogensen Sizer probability screening machine
Solids feedrate: 83.44 tonnes/h
Water feed rate: 12 tonnes/h

Size interval	1		2	3	4	5		
Upper bound	50800 mu		12700 mu	2380 mu	595 mu	149 mu		
S.G. interval	1	2	3	4	5	6	7	8
Upper bound	2.6	1.8	1.7	1.6	1.5	1.4	1.35	1.3

Number of screens: 3 Frequency: 1.5 kHz Amplitude: 3 mm Width: 2.0 m

Aperture: 12700 μ (all screens) % water in oversize: 3%

Primary element and characteristic analyses for the screen

Weight frequency (%)

	1	2	3	4	5	6	7	8
1	8.862	0.463	0.752	1.369	2.941	1.920	5.944	7.428
2	8.129	0.572	0.771	1.358	3.048	2.708	8.398	11.922
3	2.686	0.205	0.273	0.456	0.987	1.010	3.299	6.982
4	1.110	0.079	0.121	0.222	0.468	0.744	1.419	5.036
5	1.075	0.054	0.097	0.206	0.481	1.173	1.915	3.499

Ash analyses (%)

1	69.61	43.01	33.81	26.02	15.92	9.35	4.64	2.62
2	75.21	41.92	33.75	25.82	15.75	9.59	4.75	2.47
3	75.68	41.88	33.46	25.02	15.56	9.05	4.44	1.95
4	64.40	38.13	30.71	23.81	15.55	8.52	5.61	1.86
5	62.19	35.16	26.63	19.47	12.16	4.86	3.21	1.43

Calorific data (Btu/lb)

1	2841.	8269.	9723.	11077.	12682.	13909.	14907.	15355.
2	2397.	8269.	9723.	11077.	12682.	13909.	14907.	15355.
3	2272.	8269.	9723.	11077.	12682.	13909.	14907.	15355.
4	2285.	8269.	9723.	11077.	12682.	13909.	14907.	15355.
5	2027.	8269.	9723.	11077.	12682.	13909.	14907.	15355.

MOGENSEN SIZER MODEL (MOGENS)

PROGRAM DESCRIPTION: THIS ROUTINE SIMULATES THE OPERATION OF A LINEAR, MULTI-DECK, PROBABILITY SCREENING MACHINE KNOWN AS THE MOGENSEN SIZER. IT DIFFERS FROM CONVENTIONAL SCREENING MACHINES PRINCIPALLY IN THE STEEPER ANGLE OF INCLINATION OF THE SCREEN AND IN THE DIRECTION, AMPLITUDE AND FREQUENCY OF THE VIBRATIONS. THE SCREEN ANGLES ARE 18,24,30,32.5 AND 34 DEG., WITH VIBRATIONS IN A DIRECTION PREDOMINANTLY NORMAL TO THE PLANE OF THE SCREEN AT A FREQUENCY IN THE RANGE 15-30 HZ WITH AN AMPLITUDE OF 2-5 MM. BECAUSE OF THE STEEPER ANGLES OF INCLINATION AND THE LOWER AMPLITUDES OF VIBRATION COMPARED TO CONVENTIONAL SCREENING MACHINES, THE PROBABILITY SCREENING MACHINE SACRIFICES A DEGREE OF SCREENING ACCURACY IN FAVOUR OF HIGHER THROUGHPUT AND REDUCED BLINDING.

THE PROGRAMS AND SUBROUTINES REQUIRED:

XMOGENS,RDFILE,UDRIVR,MOGENS,MG2OUT,MGNOUT,DETOUT

THE VARIABLES REQUIRED ARE AS FOLLOWS:

```
NS     = NUMBER OF SIZE FRACTIONS (PAN INCLUDED)
NG     = NUMBER OF SPECIFIC GRAVITY FRACTIONS
NC     = NUMBER OF CHARACTERISTICS
SOL    = FEEDS = MASS FLOW RATE OF SOLIDS IN FEED
WAT    = FEEDW = MASS FLOW RATE OF WATER IN FEED

FEED   = 3-DIMENSIONAL ARRAY CONTAINING THE SOLIDS
         CHARACTERISTICS "ASSAYS" FOR THE FEED STREAM
         (RESIDES ON A DISK FILE AS FOLLOWS:  NC SETS
          OF NS RECORDS EACH RECORD HAVING NG VALUES)

PARAM  = PARAMETER VECTOR   - 1 = FREQ
                              2 = AMPL
                              3 = W
                4 TO (3+NSCR) = ANGLE
        (4+NSCR) TO (3+2*NSCR) = APER
      (4+2*NSCR) TO (3+3*NSCR) = WATOF
      (4+3*NSCR) TO (8+3*NSCR) = FS
     (9+3*NSCR) TO (13+3*NSCR) = EL
 FREQ    = FREQUENCY OF VIBRATION (CYCLE/MIN)
 AMPL    = AMPLITUDE OF VIBRATION (MM)
 W       = SCREEN WIDTH (M)
 ANGLE   = VECTOR OF SCREEN INCLINATION (DEGREES)
 APER    = VECTOR OF SCREEN APERTURES (MICROMETRES)
 WATOF   = VECTOR OF % MOISTURE IN THE OVERFLOW PRODUCTS
           FROM THE SCREEN
 FS      = VECTOR OF SCREEN LOADINGS  (TONNES/HR)
 EL      = VECTOR OF SCREEN LENGTHS (M)
```

```
     OPT     = OPTION VECTOR      - 1 = FLAG
                                    2 = MODE
                                    3 = RCYC
                                    4 = NI
                                    5 = NSCR
     FLAG    = FLAG TO REQUEST DETAILED OUTPUT ON PRODUCT STREAMS
               0 :  SUMMARY OUTPUT
               1 :  SUMMARY PLUS DETAILED OUTPUT
     MODE    = FLAG TO REQUEST COMBINED OVERFLOWS
               1 :  OVERFLOWS ARE COMBINED
               0 :  OVERFLOWS NOT COMBINED
     RCYC    = FLAG TO REQUEST RECOMPUTATION OF CHARACTERISTIC
               POINTS AFTER INDIVIDUAL SCREEN FLOWS HAVE BEEN
               CALCULATED ON THE FIRST PASS
               0 :  NO RECALCULATIONS PERFORMED
               1 :  CHARACTERISTIC CURVE RECALCULATED
     NI      = NUMBER OF INTEGRATION INTERVALS PER SIZE INTERVAL
     NSCR    = NUMBER OF SCREENS USED

     XMU     = VECTOR OF UPPER SIZES FOR THE INTERVALS (MICROMETRES)
     SG      = VECTOR OF UPPER SPECIFIC GRAVITIES FOR THE INTERVAL


             DATA ENTRY FOR : MOGENS


 THE DEFAULT VALUES OF NS,NG,NC,SOL & WAT ARE:

5 8 3 83.4 12.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
8.862 .463 .752 1.369 2.941 1.92 5.944 7.428
8.129 .572 .771 1.358 3.048 2.708 8.398 11.922
2.686 .205 .273 .456 .987 1.01 3.299 6.982
1.11 .079 .121 .222 .468 .744 1.419 5.036
1.075 .054 .097 .206 .481 1.173 1.915 3.499
69.61 43. 33.81 26.02 15.92 9.35 4.64 2.63
75.21 41.92 33.75 25.82 15.75 9.59 4.75 2.47
75.68 41.88 33.75 25.82 15.75 9.59 4.75 2.47
64.4 38.13 30.71 23.81 15.55 8.52 5.61 1.86
62.19 35.16 26.63 19.47 12.16 4.86 3.21 1.43
2841. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
2397. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
2272. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
2285. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
2027. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
1.5 3. 2. 21. 28. 31. 12700. 12700. 12700. 3. 0. 0. 1. .8 .6
.4 .4 1.15 1.25 1.25 1.25 1.25
 CHANGE?(Y/N)
n
```

```
 THE DEFAULT VALUES OF THE OPTIONS  RELATED TO THIS SIMULATOR ARE:
1. 1. 1. 7. 3.
 CHANGE?(Y/N)
y

 RE-ENTER THESE DATA INCLUDING CHANGES
1 0 1 7 3

 ARE THESE CORRECT?(Y/N)
y

 THE DEFAULT VALUES FOR THE ARRAY OF SIZES ARE:

50800. 12700. 2380. 595. 149.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SPECIFIC GRAVITIES ARE:
2.6 1.8 1.7 1.6 1.5 1.4 1.35 1.3
 CHANGE?(Y/N)
n

                           OUTPUT FROM MOGENSEN SIZER (MOGENS)

--------------------------------------------------------------------------------

                       ALL MASS FLOWRATES IN TONNES/HOUR

                           SCREEN CHARACTERISTICS

   WIDTH =    2.0 M     FREQUENCY =   1.5 CYCLE/MIN   AMPLITUDE =   3.0 MM

  SCREEN                ANGLE          APERTURE                  LENGTH
                        (DEGREES)      (MICRONS)                 (METRES)
--------------------------------------------------------------------------------

       1                21.00            12700.00                  1.15
       2                28.00            12700.00                  1.25
       3                31.00            12700.00                  1.25
```

```
                 FEED STREAM
                 SOLIDS FLOWRATE=  83.4
                 WATER FLOWRATE =  12.0

                 !   !  !   !  !   !
                 !   !  !   !  !   !
                 !   !  !   !  !   !
                 V   V  V   V  V   V


   SCREEN NUMBER  1                             SOLIDS FLOWRATE =  32.2
   - -- -- -- -- -- -- -- -- -- -- -- -         WATER FLOWRATE =   1.0

   SCREEN NUMBER  2                             SOLIDS FLOWRATE =   7.6
   - -- -- -- -- -- -- -- -- -- -- -- -         WATER FLOWRATE =   0.0

   SCREEN NUMBER  3                             SOLIDS FLOWRATE =   5.7
   - -- -- -- -- -- -- -- -- -- -- -- -         WATER FLOWRATE =   0.0

                 !   !  !   !  !   !
                 !   !  !   !  !   !
                 !   !  !   !  !   !
                 V   V  V   V  V   V


                 UNDERSIZE PRODUCT
                 SOLIDS FLOWRATE =  38.1
                 WATER FLOWRATE =  11.0
```

SOLIDS DISTRIBUTION

SIZE RANGE		FEED	OVFL 1	OVFL 2	OVFL 3	OVFL 4	OVFL 5	UNDFL
50800.	12700.	29.7	77.0	0.0	0.0	0.0	0.0	.0
12700.	2380.	36.9	23.0	100.0	99.8	0.0	0.0	26.5
2380.	595.	15.9	.0	.0	.2	0.0	0.0	34.8
595.	149.	9.2	.0	.0	.0	0.0	0.0	20.1
149.	0.	8.5	.0	.0	.0	0.0	0.0	18.6

OVERFLOW STREAM FROM SCREEN NUMBER 1

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	DIRECT VALUES CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	19.26	2.63	15355.00		
X 12700.	- 1.350	15.41	4.64	14907.00		
76.96%	- 1.400	4.98	9.35	13909.00		
	- 1.500	7.63	15.92	12682.00		
	- 1.600	3.55	26.02	11077.00		
	- 1.700	1.95	33.81	9723.00		
	- 1.800	1.20	43.00	8269.00		
	- 2.600	22.98	69.61	2841.00		
12700.	- 1.300	7.44	2.47	15355.00		
X 2380.	- 1.350	5.24	4.75	14907.00		
23.04%	- 1.400	1.69	9.59	13909.00		
	- 1.500	1.90	15.75	12682.00		
	- 1.600	.85	25.82	11077.00		
	- 1.700	.48	33.75	9723.00		
	- 1.800	.36	41.92	8269.00		
	- 2.600	5.07	75.21	2397.00		
2380.	- 1.300	.00	2.47	15355.00		
X 595.	- 1.350	.00	4.75	14907.00		
.00%	- 1.400	.00	9.59	13909.00		
	- 1.500	.00	15.75	12682.00		
	- 1.600	.00	25.82	11077.00		
	- 1.700	.00	33.75	9723.00		
	- 1.800	.00	41.88	8269.00		
	- 2.600	.00	75.68	2272.00		
595.	- 1.300	.00	1.86	15355.00		
X 149.	- 1.350	.00	5.61	14907.00		
.00%	- 1.400	.00	8.52	13909.00		
	- 1.500	.00	15.55	12682.00		
	- 1.600	.00	23.81	11077.00		
	- 1.700	.00	30.71	9723.00		
	- 1.800	.00	38.13	8269.00		
	- 2.600	.00	64.40	2285.00		
149.	- 1.300	.00	1.43	15355.00		
X 0.	- 1.350	.00	3.21	14907.00		
.00%	- 1.400	.00	4.86	13909.00		
	- 1.500	.00	12.16	12682.00		
	- 1.600	.00	19.47	11077.00		
	- 1.700	.00	26.63	9723.00		
	- 1.800	.00	35.16	8269.00		
	- 2.600	.00	62.19	2027.00		

CUMULATIVE VALUES

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	25.03	2.63	15355.00		
X 12700.	- 1.350	45.06	3.52	15155.86		
76.96%	- 1.400	51.52	4.26	14999.31		
	- 1.500	61.43	6.14	14625.52		
	- 1.600	66.05	7.53	14377.70		
	- 1.700	68.58	8.50	14205.72		
	- 1.800	70.14	9.26	14073.68		
	- 2.600	100.00	27.28	10719.66		
12700.	- 1.300	32.30	2.47	15355.00		
X 2380.	- 1.350	55.06	3.41	15169.85		
23.04%	- 1.400	62.40	4.14	15021.58		
	- 1.500	70.66	5.50	14748.11		
	- 1.600	74.33	6.50	14566.38		
	- 1.700	76.42	7.25	14433.99		
	- 1.800	77.97	7.94	14311.45		
	- 2.600	100.00	22.75	11687.14		
2380.	- 1.300	43.92	2.47	15355.00		
X 595.	- 1.350	64.67	3.20	15211.24		
.00%	- 1.400	71.02	3.77	15094.76		
	- 1.500	77.23	4.74	14900.80		
	- 1.600	80.10	5.49	14763.87		
	- 1.700	81.82	6.08	14658.07		
	- 1.800	83.10	6.64	14558.94		
	- 2.600	100.00	18.30	12483.03		
595.	- 1.300	54.75	1.86	15355.00		
X 149.	- 1.350	70.17	2.68	15256.52		
.00%	- 1.400	78.26	3.29	15117.25		
	- 1.500	83.35	4.04	14968.60		
	- 1.600	85.76	4.59	14859.09		
	- 1.700	87.07	4.99	14781.51		
	- 1.800	87.93	5.31	14717.90		
	- 2.600	100.00	12.44	13217.68		
149.	- 1.300	41.16	1.43	15355.00		
X 0.	- 1.350	63.69	2.06	15196.54		
.00%	- 1.400	77.49	2.56	14967.25		
	- 1.500	83.15	3.21	14811.74		
	- 1.600	85.58	3.67	14705.97		
	- 1.700	86.72	3.97	14640.39		
	- 1.800	87.35	4.20	14594.06		
	- 2.600	100.00	11.53	13004.69		

OVERFLOW STREAM FROM SCREEN NUMBER 2

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	DIRECT VALUES CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	0.00	2.63	15355.00		
X 12700.	- 1.350	0.00	4.64	14907.00		
0.00%	- 1.400	0.00	9.35	13909.00		
	- 1.500	0.00	15.92	12682.00		
	- 1.600	0.00	26.02	11077.00		
	- 1.700	0.00	33.81	9723.00		
	- 1.800	0.00	43.00	8269.00		
	- 2.600	0.00	69.61	2841.00		
12700.	- 1.300	32.30	2.47	15355.00		
X 2380.	- 1.350	22.75	4.75	14907.00		
99.99%	- 1.400	7.34	9.59	13909.00		
	- 1.500	8.26	15.75	12682.00		
	- 1.600	3.68	25.82	11077.00		
	- 1.700	2.09	33.75	9723.00		
	- 1.800	1.55	41.92	8269.00		
	- 2.600	22.02	75.21	2397.00		
2380.	- 1.300	.01	2.47	15355.00		
X 595.	- 1.350	.00	4.75	14907.00		
.01%	- 1.400	.00	9.59	13909.00		
	- 1.500	.00	15.75	12682.00		
	- 1.600	.00	25.82	11077.00		
	- 1.700	.00	33.75	9723.00		
	- 1.800	.00	41.88	8269.00		
	- 2.600	.00	75.68	2272.00		
595.	- 1.300	.00	1.86	15355.00		
X 149.	- 1.350	.00	5.61	14907.00		
.00%	- 1.400	.00	8.52	13909.00		
	- 1.500	.00	15.55	12682.00		
	- 1.600	.00	23.81	11077.00		
	- 1.700	.00	30.71	9723.00		
	- 1.800	.00	38.13	8269.00		
	- 2.600	.00	64.40	2285.00		
149.	- 1.300	.00	1.43	15355.00		
X 0.	- 1.350	.00	3.21	14907.00		
.00%	- 1.400	.00	4.86	13909.00		
	- 1.500	.00	12.16	12682.00		
	- 1.600	.00	19.47	11077.00		
	- 1.700	.00	26.63	9723.00		
	- 1.800	.00	35.16	8269.00		
	- 2.600	.00	62.19	2027.00		

CUMULATIVE VALUES

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	0.00	0.00	0.00		
X 12700.	- 1.350	0.00	0.00	0.00		
0.00%	- 1.400	0.00	0.00	0.00		
	- 1.500	0.00	0.00	0.00		
	- 1.600	0.00	0.00	0.00		
	- 1.700	0.00	0.00	0.00		
	- 1.800	0.00	0.00	0.00		
	- 2.600	0.00	0.00	0.00		
12700.	- 1.300	32.30	2.47	15355.00		
X 2380.	- 1.350	55.06	3.41	15169.85		
99.99%	- 1.400	62.40	4.14	15021.58		
	- 1.500	70.66	5.50	14748.11		
	- 1.600	74.33	6.50	14566.38		
	- 1.700	76.42	7.25	14433.99		
	- 1.800	77.97	7.94	14311.45		
	- 2.600	100.00	22.75	11687.14		
2380.	- 1.300	43.92	2.47	15355.00		
X 595.	- 1.350	64.67	3.20	15211.24		
.01%	- 1.400	71.02	3.77	15094.76		
	- 1.500	77.23	4.74	14900.80		
	- 1.600	80.10	5.49	14763.87		
	- 1.700	81.82	6.08	14658.07		
	- 1.800	83.10	6.64	14558.94		
	- 2.600	100.00	18.30	12483.03		
595.	- 1.300	54.75	1.86	15355.00		
X 149.	- 1.350	70.17	2.68	15256.52		
.00%	- 1.400	78.26	3.29	15117.25		
	- 1.500	83.35	4.04	14968.60		
	- 1.600	85.76	4.59	14859.09		
	- 1.700	87.07	4.99	14781.51		
	- 1.800	87.93	5.31	14717.90		
	- 2.600	100.00	12.44	13217.68		
149.	- 1.300	41.16	1.43	15355.00		
X 0.	- 1.350	63.69	2.06	15196.54		
.00%	- 1.400	77.49	2.56	14967.25		
	- 1.500	83.15	3.21	14811.74		
	- 1.600	85.58	3.67	14705.97		
	- 1.700	86.72	3.97	14640.39		
	- 1.800	87.35	4.20	14594.06		
	- 2.600	100.00	11.53	13004.69		

OVERFLOW STREAM FROM SCREEN NUMBER 3

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	DIRECT VALUES CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	0.00	2.63	15355.00		
X 12700.	- 1.350	0.00	4.64	14907.00		
0.00%	- 1.400	0.00	9.35	13909.00		
	- 1.500	0.00	15.92	12682.00		
	- 1.600	0.00	26.02	11077.00		
	- 1.700	0.00	33.81	9723.00		
	- 1.800	0.00	43.00	8269.00		
	- 2.600	0.00	69.61	2841.00		
12700.	- 1.300	32.23	2.47	15355.00		
X 2380.	- 1.350	22.70	4.75	14907.00		
99.78%	- 1.400	7.32	9.59	13909.00		
	- 1.500	8.24	15.75	12682.00		
	- 1.600	3.67	25.82	11077.00		
	- 1.700	2.08	33.75	9723.00		
	- 1.800	1.55	41.92	8269.00		
	- 2.600	21.98	75.21	2397.00		
2380.	- 1.300	.10	2.47	15355.00		
X 595.	- 1.350	.05	4.75	14907.00		
.22%	- 1.400	.01	9.59	13909.00		
	- 1.500	.01	15.75	12682.00		
	- 1.600	.01	25.82	11077.00		
	- 1.700	.00	33.75	9723.00		
	- 1.800	.00	41.88	8269.00		
	- 2.600	.04	75.68	2272.00		
595.	- 1.300	.00	1.86	15355.00		
X 149.	- 1.350	.00	5.61	14907.00		
.00%	- 1.400	.00	8.52	13909.00		
	- 1.500	.00	15.55	12682.00		
	- 1.600	.00	23.81	11077.00		
	- 1.700	.00	30.71	9723.00		
	- 1.800	.00	38.13	8269.00		
	- 2.600	.00	64.40	2285.00		
149.	- 1.300	.00	1.43	15355.00		
X 0.	- 1.350	.00	3.21	14907.00		
.00%	- 1.400	.00	4.86	13909.00		
	- 1.500	.00	12.16	12682.00		
	- 1.600	.00	19.47	11077.00		
	- 1.700	.00	26.63	9723.00		
	- 1.800	.00	35.16	8269.00		
	- 2.600	.00	62.19	2027.00		

			CUMULATIVE VALUES			
SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	0.00	0.00	0.00		
X 12700.	- 1.350	0.00	0.00	0.00		
0.00%	- 1.400	0.00	0.00	0.00		
	- 1.500	0.00	0.00	0.00		
	- 1.600	0.00	0.00	0.00		
	- 1.700	0.00	0.00	0.00		
	- 1.800	0.00	0.00	0.00		
	- 2.600	0.00	0.00	0.00		
12700.	- 1.300	32.30	2.47	15355.00		
X 2380.	- 1.350	55.06	3.41	15169.85		
99.78%	- 1.400	62.40	4.14	15021.58		
	- 1.500	70.66	5.50	14748.11		
	- 1.600	74.33	6.50	14566.38		
	- 1.700	76.42	7.25	14433.99		
	- 1.800	77.97	7.94	14311.45		
	- 2.600	100.00	22.75	11687.14		
2380.	- 1.300	43.92	2.47	15355.00		
X 595.	- 1.350	64.67	3.20	15211.24		
.22%	- 1.400	71.02	3.77	15094.76		
	- 1.500	77.23	4.74	14900.80		
	- 1.600	80.10	5.49	14763.87		
	- 1.700	81.82	6.08	14658.07		
	- 1.800	83.10	6.64	14558.94		
	- 2.600	100.00	18.30	12483.03		
595.	- 1.300	54.75	1.86	15355.00		
X 149.	- 1.350	70.17	2.68	15256.52		
.00%	- 1.400	78.26	3.29	15117.25		
	- 1.500	83.35	4.04	14968.60		
	- 1.600	85.76	4.59	14859.09		
	- 1.700	87.07	4.99	14781.51		
	- 1.800	87.93	5.31	14717.90		
	- 2.600	100.00	12.44	13217.68		
149.	- 1.300	41.16	1.43	15355.00		
X 0.	- 1.350	63.69	2.06	15196.54		
.00%	- 1.400	77.49	2.56	14967.25		
	- 1.500	83.15	3.21	14811.74		
	- 1.600	85.58	3.67	14705.97		
	- 1.700	86.72	3.97	14640.39		
	- 1.800	87.35	4.20	14594.06		
	- 2.600	100.00	11.53	13004.69		

SCREEN UNDERSIZE STREAM

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	DIRECT VALUES CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	.00	2.63	15355.00		
X 12700.	- 1.350	.00	4.64	14907.00		
.00%	- 1.400	.00	9.35	13909.00		
	- 1.500	.00	15.92	12682.00		
	- 1.600	.00	26.02	11077.00		
	- 1.700	.00	33.81	9723.00		
	- 1.800	.00	43.00	8269.00		
	- 2.600	.00	69.61	2841.00		
12700.	- 1.300	8.56	2.47	15355.00		
X 2380.	- 1.350	6.03	4.75	14907.00		
26.49%	- 1.400	1.94	9.59	13909.00		
	- 1.500	2.19	15.75	12682.00		
	- 1.600	.97	25.82	11077.00		
	- 1.700	.55	33.75	9723.00		
	- 1.800	.41	41.92	8269.00		
	- 2.600	5.84	75.21	2397.00		
2380.	- 1.300	15.27	2.47	15355.00		
X 595.	- 1.350	7.21	4.75	14907.00		
34.76%	- 1.400	2.21	9.59	13909.00		
	- 1.500	2.16	15.75	12682.00		
	- 1.600	1.00	25.82	11077.00		
	- 1.700	.60	33.75	9723.00		
	- 1.800	.45	41.88	8269.00		
	- 2.600	5.87	75.68	2272.00		
595.	- 1.300	11.02	1.86	15355.00		
X 149.	- 1.350	3.11	5.61	14907.00		
20.14%	- 1.400	1.63	8.52	13909.00		
	- 1.500	1.02	15.55	12682.00		
	- 1.600	.49	23.81	11077.00		
	- 1.700	.26	30.71	9723.00		
	- 1.800	.17	38.13	8269.00		
	- 2.600	2.43	64.40	2285.00		
149.	- 1.300	7.66	1.43	15355.00		
X 0.	- 1.350	4.19	3.21	14907.00		
18.61%	- 1.400	2.57	4.86	13909.00		
	- 1.500	1.05	12.16	12682.00		
	- 1.600	.45	19.47	11077.00		
	- 1.700	.21	26.63	9723.00		
	- 1.800	.12	35.16	8269.00		
	- 2.600	2.35	62.19	2027.00		

CUMULATIVE VALUES

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	25.03	2.63	15355.00		
X 12700.	- 1.350	45.06	3.52	15155.86		
.00%	- 1.400	51.52	4.26	14999.31		
	- 1.500	61.43	6.14	14625.52		
	- 1.600	66.05	7.53	14377.70		
	- 1.700	68.58	8.50	14205.72		
	- 1.800	70.14	9.26	14073.68		
	- 2.600	100.00	27.28	10719.66		
12700.	- 1.300	32.30	2.47	15355.00		
X 2380.	- 1.350	55.06	3.41	15169.85		
26.49%	- 1.400	62.40	4.14	15021.58		
	- 1.500	70.66	5.50	14748.11		
	- 1.600	74.33	6.50	14566.38		
	- 1.700	76.42	7.25	14433.99		
	- 1.800	77.97	7.94	14311.45		
	- 2.600	100.00	22.75	11687.14		
2380.	- 1.300	43.92	2.47	15355.00		
X 595.	- 1.350	64.67	3.20	15211.24		
34.76%	- 1.400	71.02	3.77	15094.76		
	- 1.500	77.23	4.74	14900.80		
	- 1.600	80.10	5.49	14763.87		
	- 1.700	81.82	6.08	14658.07		
	- 1.800	83.10	6.64	14558.94		
	- 2.600	100.00	18.30	12483.03		
595.	- 1.300	54.75	1.86	15355.00		
X 149.	- 1.350	70.17	2.68	15256.52		
20.14%	- 1.400	78.26	3.29	15117.25		
	- 1.500	83.35	4.04	14968.60		
	- 1.600	85.76	4.59	14859.09		
	- 1.700	87.07	4.99	14781.51		
	- 1.800	87.93	5.31	14717.90		
	- 2.600	100.00	12.44	13217.68		
149.	- 1.300	41.16	1.43	15355.00		
X 0.	- 1.350	63.69	2.06	15196.54		
18.61%	- 1.400	77.49	2.56	14967.25		
	- 1.500	83.15	3.21	14811.74		
	- 1.600	85.58	3.67	14705.97		
	- 1.700	86.72	3.97	14640.39		
	- 1.800	87.35	4.20	14594.06		
	- 2.600	100.00	11.53	13004.69		

```
STOP
044300 MAXIMUM EXECUTION FL.
 2.143 CP SECONDS EXECUTION TIME.
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            DATA ENTRY FOR : MOGENS


 THE DEFAULT VALUES OF NS,NG,NC,SOL & WAT ARE:

5 8 3 83.4 12.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
8.862 .463 .752 1.369 2.941 1.92 5.944 7.428
8.129 .572 .771 1.358 3.048 2.708 8.398 11.922
2.686 .205 .273 .456 .987 1.01 3.299 6.982
1.11 .079 .121 .222 .468 .744 1.419 5.036
1.075 .054 .097 .206 .481 1.173 1.915 3.499
69.61 43. 33.81 26.02 15.92 9.35 4.64 2.63
75.21 41.92 33.75 25.82 15.75 9.59 4.75 2.47
75.68 41.88 33.75 25.82 15.75 9.59 4.75 2.47
64.4 38.13 30.71 23.81 15.55 8.52 5.61 1.86
62.19 35.16 26.63 19.47 12.16 4.86 3.21 1.43
2841. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
2397. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
2272. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
2285. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
2027. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
1.5 3. 2. 21. 28. 31. 12700. 12700. 12700. 3. 0. 0. 1. .8 .6
.4 .4 1.15 1.25 1.25 1.25 1.25
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE OPTIONS  RELATED TO THIS SIMULATOR ARE:
1. 1. 1. 7. 3.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SIZES ARE:

50800. 12700. 2380. 595. 149.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SPECIFIC GRAVITIES ARE:
2.6 1.8 1.7 1.6 1.5 1.4 1.35 1.3
 CHANGE?(Y/N)
n
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OUTPUT FROM MOGENSEN SIZER (MOGENS)
OVERFLOW STREAMS ARE COMBINED

ALL MASS FLOWRATES IN TONNES/HOUR

SCREEN CHARACTERISTICS

SCREEN	ANGLE (DEGREES)	APERTURE (MICRONS)	LENGTH (METRES)
1	21.00	12700.00	1.15
2	28.00	12700.00	1.25
3	31.00	12700.00	1.25

```
                                         FEED STREAM
                                         SOLIDS FLOWRATE=   83.4
                                         WATER FLOWRATE =   12.0
                                         !   !  !   !  !   !
                                         !   !  !   !  !   !
                                         !   !  !   !  !   !
                                         V   V  V   V  V   V
WIDTH =  2.00 (M)
FREQUENCY = 1.50 CYCLE/MIN                                                ==========I
                               - -- -- -- -- -- -- -- -- -- -- --  ========= I
AMPLITUDE =  3.00 MM                                                              I I
% WATER(O/S) =  3.00                                                              I I
                                                                                  I I
                                         !   !  !   !  !   !                      I I
                                         !   !  !   !  !   !                      I I
                                         !   !  !   !  !   !                      I I
                                         V   V  V   V  V   V                      V V
                                         UNDERSIZE PRODUCT         OVERSIZE PRODUCT
                                         SOLIDS FLOWRATE= 38.10    SOLIDS FLOWRATE= 45.45
                                         WATER FLOWRATE = 11.01    WATER FLOWRATE =    .99
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SOLIDS DISTRIBUTION

SIZE RANGE	FEED WT. (%)	FEED ASH %	UNDER WT. (%)	UNDER ASH %	OVER WT. (%)	OVER ASH %
50800. - 12700.	29.68	27.28	.00	27.28	54.46	27.28
12700. - 2380.	36.91	22.75	26.49	22.75	45.51	22.75
2380. - 595.	15.90	18.30	34.76	18.30	.03	18.30
595. - 149.	9.20	12.44	20.14	12.44	.00	12.44
149. - 0.	8.50	11.53	18.61	11.53	.00	11.53
CUMULATIVE VALUES:	100.18	21.49	100.00	17.04	100.00	25.22

CHAR.# 2   FEED=11779.15 COAL=12517.17 ROCK=11160.52

SCREEN OVERSIZE STREAM

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	DIRECT VALUES CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	13.63	2.63	15355.00		
X 12700.	- 1.350	10.91	4.64	14907.00		
54.46%	- 1.400	3.52	9.35	13909.00		
	- 1.500	5.40	15.92	12682.00		
	- 1.600	2.51	26.02	11077.00		
	- 1.700	1.38	33.81	9723.00		
	- 1.800	.85	43.00	8269.00		
	- 2.600	16.26	69.61	2841.00		
12700.	- 1.300	14.70	2.47	15355.00		
X 2380.	- 1.350	10.36	4.75	14907.00		
45.51%	- 1.400	3.34	9.59	13909.00		
	- 1.500	3.76	15.75	12682.00		
	- 1.600	1.67	25.82	11077.00		
	- 1.700	.95	33.75	9723.00		
	- 1.800	.71	41.92	8269.00		
	- 2.600	10.02	75.21	2397.00		
2380.	- 1.300	.01	2.47	15355.00		
X 595.	- 1.350	.01	4.75	14907.00		
.03%	- 1.400	.00	9.59	13909.00		
	- 1.500	.00	15.75	12682.00		
	- 1.600	.00	25.82	11077.00		
	- 1.700	.00	33.75	9723.00		
	- 1.800	.00	41.88	8269.00		
	- 2.600	.01	75.68	2272.00		
595.	- 1.300	.00	1.86	15355.00		
X 149.	- 1.350	.00	5.61	14907.00		
.00%	- 1.400	.00	8.52	13909.00		
	- 1.500	.00	15.55	12682.00		
	- 1.600	.00	23.81	11077.00		
	- 1.700	.00	30.71	9723.00		
	- 1.800	.00	38.13	8269.00		
	- 2.600	.00	64.40	2285.00		
149.	- 1.300	.00	1.43	15355.00		
X 0.	- 1.350	.00	3.21	14907.00		
.00%	- 1.400	.00	4.86	13909.00		
	- 1.500	.00	12.16	12682.00		
	- 1.600	.00	19.47	11077.00		
	- 1.700	.00	26.63	9723.00		
	- 1.800	.00	35.16	8269.00		
	- 2.600	.00	62.19	2027.00		

CUMULATIVE VALUES

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	25.03	2.63	15355.00		
X 12700.	- 1.350	45.06	3.52	15155.86		
54.46%	- 1.400	51.52	4.26	14999.31		
	- 1.500	61.43	6.14	14625.52		
	- 1.600	66.05	7.53	14377.70		
	- 1.700	68.58	8.50	14205.72		
	- 1.800	70.14	9.26	14073.68		
	- 2.600	100.00	27.28	10719.66		
12700.	- 1.300	32.30	2.47	15355.00		
X 2380.	- 1.350	55.06	3.41	15169.85		
45.51%	- 1.400	62.40	4.14	15021.58		
	- 1.500	70.66	5.50	14748.11		
	- 1.600	74.33	6.50	14566.38		
	- 1.700	76.42	7.25	14433.99		
	- 1.800	77.97	7.94	14311.45		
	- 2.600	100.00	22.75	11687.14		
2380.	- 1.300	43.92	2.47	15355.00		
X 595.	- 1.350	64.67	3.20	15211.24		
.03%	- 1.400	71.02	3.77	15094.76		
	- 1.500	77.23	4.74	14900.80		
	- 1.600	80.10	5.49	14763.87		
	- 1.700	81.82	6.08	14658.07		
	- 1.800	83.10	6.64	14558.94		
	- 2.600	100.00	18.30	12483.03		
595.	- 1.300	54.75	1.86	15355.00		
X 149.	- 1.350	70.17	2.68	15256.52		
.00%	- 1.400	78.26	3.29	15117.25		
	- 1.500	83.35	4.04	14968.60		
	- 1.600	85.76	4.59	14859.09		
	- 1.700	87.07	4.99	14781.51		
	- 1.800	87.93	5.31	14717.90		
	- 2.600	100.00	12.44	13217.68		
149.	- 1.300	41.16	1.43	15355.00		
X 0.	- 1.350	63.69	2.06	15196.54		
.00%	- 1.400	77.49	2.56	14967.25		
	- 1.500	83.15	3.21	14811.74		
	- 1.600	85.58	3.67	14705.97		
	- 1.700	86.72	3.97	14640.39		
	- 1.800	87.35	4.20	14594.06		
	- 2.600	100.00	11.53	13004.69		

SCREEN UNDERSIZE STREAM

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	DIRECT VALUES CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	.00	2.63	15355.00		
X 12700.	- 1.350	.00	4.64	14907.00		
.00%	- 1.400	.00	9.35	13909.00		
	- 1.500	.00	15.92	12682.00		
	- 1.600	.00	26.02	11077.00		
	- 1.700	.00	33.81	9723.00		
	- 1.800	.00	43.00	8269.00		
	- 2.600	.00	69.61	2841.00		
12700.	- 1.300	8.56	2.47	15355.00		
X 2380.	- 1.350	6.03	4.75	14907.00		
26.49%	- 1.400	1.94	9.59	13909.00		
	- 1.500	2.19	15.75	12682.00		
	- 1.600	.97	25.82	11077.00		
	- 1.700	.55	33.75	9723.00		
	- 1.800	.41	41.92	8269.00		
	- 2.600	5.84	75.21	2397.00		
2380.	- 1.300	15.27	2.47	15355.00		
X 595.	- 1.350	7.21	4.75	14907.00		
34.76%	- 1.400	2.21	9.59	13909.00		
	- 1.500	2.16	15.75	12682.00		
	- 1.600	1.00	25.82	11077.00		
	- 1.700	.60	33.75	9723.00		
	- 1.800	.45	41.88	8269.00		
	- 2.600	5.87	75.68	2272.00		
595.	- 1.300	11.02	1.86	15355.00		
X 149.	- 1.350	3.11	5.61	14907.00		
20.14%	- 1.400	1.63	8.52	13909.00		
	- 1.500	1.02	15.55	12682.00		
	- 1.600	.49	23.81	11077.00		
	- 1.700	.26	30.71	9723.00		
	- 1.800	.17	38.13	8269.00		
	- 2.600	2.43	64.40	2285.00		
149.	- 1.300	7.66	1.43	15355.00		
X 0.	- 1.350	4.19	3.21	14907.00		
18.61%	- 1.400	2.57	4.86	13909.00		
	- 1.500	1.05	12.16	12682.00		
	- 1.600	.45	19.47	11077.00		
	- 1.700	.21	26.63	9723.00		
	- 1.800	.12	35.16	8269.00		
	- 2.600	2.35	62.19	2027.00		

CUMULATIVE VALUES

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	25.03	2.63	15355.00		
X 12700.	- 1.350	45.06	3.52	15155.86		
.00%	- 1.400	51.52	4.26	14999.31		
	- 1.500	61.43	6.14	14625.52		
	- 1.600	66.05	7.53	14377.70		
	- 1.700	68.58	8.50	14205.72		
	- 1.800	70.14	9.26	14073.68		
	- 2.600	100.00	27.28	10719.66		
12700.	- 1.300	32.30	2.47	15355.00		
X 2380.	- 1.350	55.06	3.41	15169.85		
26.49%	- 1.400	62.40	4.14	15021.58		
	- 1.500	70.66	5.50	14748.11		
	- 1.600	74.33	6.50	14566.38		
	- 1.700	76.42	7.25	14433.99		
	- 1.800	77.97	7.94	14311.45		
	- 2.600	100.00	22.75	11687.14		
2380.	- 1.300	43.92	2.47	15355.00		
X 595.	- 1.350	64.67	3.20	15211.24		
34.76%	- 1.400	71.02	3.77	15094.76		
	- 1.500	77.23	4.74	14900.80		
	- 1.600	80.10	5.49	14763.87		
	- 1.700	81.82	6.08	14658.07		
	- 1.800	83.10	6.64	14558.94		
	- 2.600	100.00	18.30	12483.03		
595.	- 1.300	54.75	1.86	15355.00		
X 149.	- 1.350	70.17	2.68	15256.52		
20.14%	- 1.400	78.26	3.29	15117.25		
	- 1.500	83.35	4.04	14968.60		
	- 1.600	85.76	4.59	14859.09		
	- 1.700	87.07	4.99	14781.51		
	- 1.800	87.93	5.31	14717.90		
	- 2.600	100.00	12.44	13217.68		
149.	- 1.300	41.16	1.43	15355.00		
X 0.	- 1.350	63.69	2.06	15196.54		
18.61%	- 1.400	77.49	2.56	14967.25		
	- 1.500	83.15	3.21	14811.74		
	- 1.600	85.58	3.67	14705.97		
	- 1.700	86.72	3.97	14640.39		
	- 1.800	87.35	4.20	14594.06		
	- 2.600	100.00	11.53	13004.69		

```
STOP
044300 MAXIMUM EXECUTION FL.
 1.418 CP SECONDS EXECUTION TIME.
```

4. BALLING DRUM (BALDRM)

4.1 PROGRAM IDENTIFICATION

Program Title:	Simulation of a **BAL**ling **DR**u**M** Circuit.
Program Code Name:	BALDRM.
Authors:	J. Wilson, R.F. Pilgrim.
Organization:	Energy, Mines and Resources, Canada Centre for Mineral and Energy Technology, Mineral Processing Laboratory.
Date:	March 1981.
Updates:	None.
Source Language:	CDC FORTRAN Extended 4.8 (American National Standard Institute FORTRAN X3.9 — 1966).
Availability:	Complete program listing is available from: CANMET, Energy, Mines and Resources, Technology Information Division, 555 Booth Street, Ottawa, Ontario, K1A 0G1.

4.2 ENGINEERING DOCUMENTATION

4.2.1 Narrative Description

A balling drum circuit (Fig. 4.1) consists of an inclined rotary drum, a discharge screen, and a return conveyor for undersize balls. The drum is fed with damp iron ore concentrate mixed with bentonite and undersize returns. As the material rolls down the drum, it forms balls which grow by several mechanisms. At the discharge end of the drum, the balls are screened and the oversize becomes the product, while the undersize is recycled to the charge end of the drum.

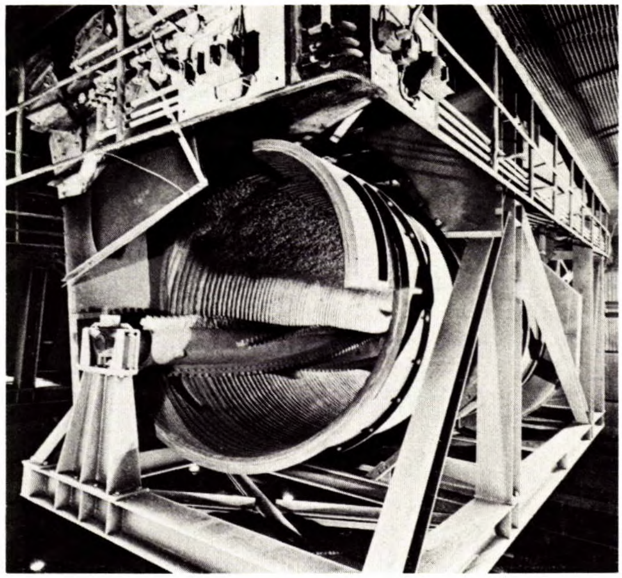
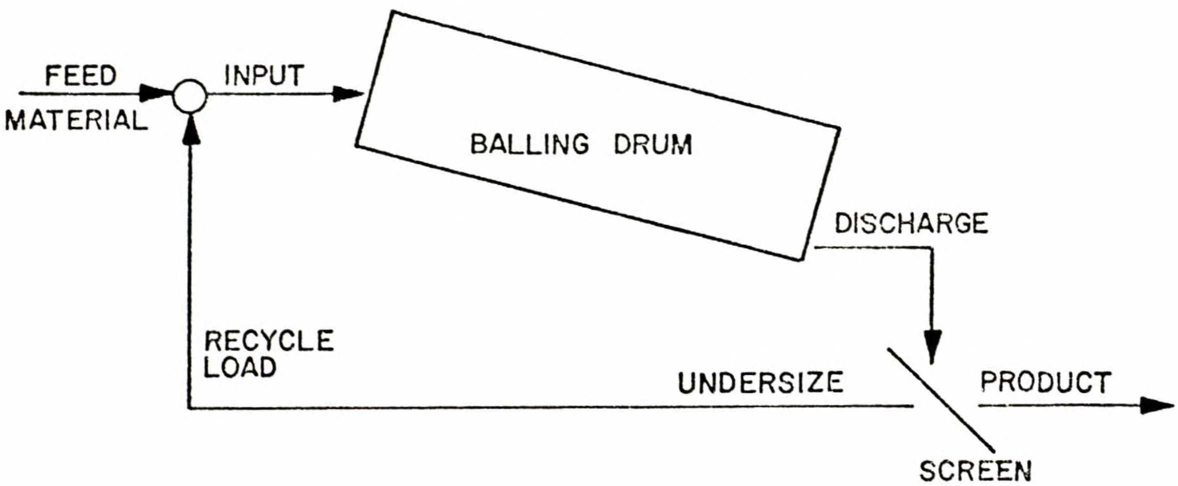


Fig. 4.1 — a) Balling drum (5)



b) Balling drum circuit

The simulator describes the output of a balling drum circuit as a function of time. It is a slightly modified version of Cross' simulator (1), which is based on green ball growth mechanisms and kinetics found in the literature (2,3,4). It incorporates two growth mechanisms which are:

1. When fresh feed is available, new seeds are produced and existing balls grow at a rate independent of their diameter, such that their relative size distribution remains constant.
2. The crushing and layering mechanism (Fig. 4.2). Specifically, in the absence of fresh feed, ball growth takes place by the crushing of the smallest balls present, and the redistribution of the material to the remaining balls in proportion to their diameter.

Growth kinetics is based on the results of the batch balling experiments of Sastry and Fuerstenau (4). Common to these growth mechanisms is the fact that ball growth is related to distance rolled.

The model follows a material sample around the circuit, evaluating the development of its pellet size distribution for each cycle. As a result of incorporating the two growth mechanisms mentioned above, Cross considers two separate growth stages: with and without fresh feed.

In the first stage, the charge contains both fresh feed and recycle balls. As the sample moves down the drum, seeds are produced at a rate proportional to the distance rolled and the amount of fresh feed available. As well, existing pellets grow at a constant rate proportional only to the distance rolled. The end of the first stage is reached when all the fresh feed is used up.

In the second stage, there are only balls left and the model assumes that mechanism 2 is operative. The overall kinetics of the balling operation, with regard to moisture and bentonite content, is determined by the results of Sastry and Fuerstenau (4). The output size distribution is calculated and then screened. The recycle and product flow rates, expressed as a percentage of feed rate, provide the computer output. The program could be modified easily to print out also the pellet size distribution at the end of each cycle.

4.2.2 Method of Solution

The ball growth in stage 1 may be expressed in terms of volumes of fresh material, of new seeds, and of new ball growth. The length of the ball drum is divided up into 100 increments, and after the sample has rolled through one of these increments, the relationship between the volumes is given by:

$$V^1 = V - \left[K_1 \, \delta \, \Delta \frac{\pi}{2} \sum_{i=1}^{M} n_i d_i^2 \right] - \left[\frac{\pi}{6} N_{m+1} \, d_N^3 \right] \qquad \text{Eq 1}$$

where: V^1 = volume of fresh feed on leaving the increment (m^3).
V = volume of fresh feed on entering the increment (m^3).
δ = distance rolled by sample per increment (m).
Δ = ball growth rate (m/m).
m = number of size classes on entering increment.
n_i = number of balls in ith size class.
d_i = diameter of balls in ith size class (m).
N_{m+1} = number of new seeds formed per increment.
d_N = diameter of seed balls (m).
K_1 = scaling factor.

The first term (in square brackets), on the right hand side of Equation 1, is the volume of the new growth added to the already existing balls during one increment. The second bracketed term is the volume of the new seeds formed during one increment.

For each increment, new seeds are formed according to:

$$N_{m+1} = MV\rho\delta/K_2 \qquad \text{Eq 2}$$

where: M = seed generation rate (1/t/m)
ρ = feed density (t/m^3)
K_2 = scaling factor.

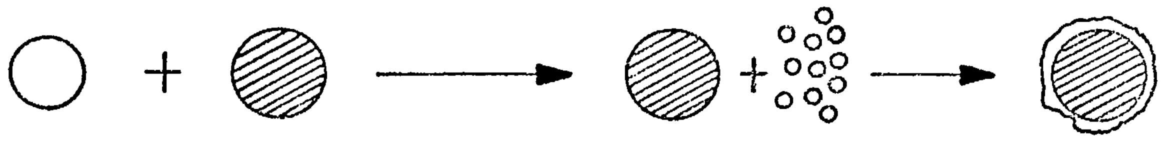


Fig. 4.2 — Growth by crushing and layering

The factor K_2 is used to scale down the number of seeds produced. Equation 1 is iterated for each increment, with V taking the value of V^1 and a new V^1 being calculated. If the end of the balling drum is reached before $V^1 = 0$, then the program jumps to the screening operating at the end of stage 2, and the fresh feed left over is recycled. Normally, stage 1 will be completed when $V^1 \leq 0$, and at that point the distance left to be rolled in the drum is

$$X_1 = K_1 d_p - I\delta$$

where: d_p = distance rolled by the average ball per pass (m)

I = number of increments rolled to end of stage 1.

The distance rolled, $I\delta$, is not used in further calculations because the results of Sastry and Fuerstenau (4) are for batch balling. Therefore, an 'equivalent' distance rolled, X_o, is calculated by using the average ball diameter at the end of stage 1.

$$d_{AV}^{(I)} = \sum_{i=1}^{m} n_i d_i / N \qquad \text{Eq 3}$$

where: N = total number of balls.

X_o is calculated by using the standard growth equation fitted to the results of Sastry and Fuerstenau (4). This is

$$D = (11.79\ WS - 109.40)\left(1 - \exp\left[-.000209\left|\frac{X}{.95755}\right|^{1.19}\right]\right)/1000 \qquad \text{Eq 4}$$

where: D = average pellet diameter (m).

WS = effective moisture content (%), calculated from water content, W, and bentonite level, B, according to the equation WS = W — .47B.

X = distance rolled (m).

The overall 'equivalent' distance is given by

$$X = X_o + X_1 \qquad \text{Eq 5}$$

Using the value of X calculated from Equation 5, Equation 4 is applied again and an average output ball diameter is calculated.

The output ball size distribution is then calculated by taking the ball size distribution at the end of stage 1, crushing ball by ball from the smallest upwards, and redistributing the crushed material to the remainder in proportion to their diameters. This is done until the average ball diameter is equal to the average ball diameter from Equation 4. To do this, the program first calculates γ, where γ is the ball growth constant in stage 2.

The crushing of the smallest balls, and transferring of the crushed material to the largest balls, must obey the conservation equation:

> Volume of material crushed = Volume of material layered.

This may be written mathematically as

$$\frac{\pi}{6}\sum_{j=k}^{m} n_j d_j^3 = \frac{\pi}{2}\sum_{i=1}^{k-1} n_i(d_i - d_{k-1})d_i^2\gamma \qquad \text{Eq 6}$$

where: k = largest class size crushed

k − 1 = smallest class size of remaining balls.

and where redistribution of crushed material is done according to the output size distribution equation.

$$d_i^{(o)} = d_i + \gamma(d_i - d_{k-1}) \text{ for } i=1, ..., k-1 \qquad \text{Eq 7}$$

The growth constant, γ, is then calculated using Equation 6 which may be written

$$\gamma = \frac{1}{3}\Sigma(n_j d_j^3) \Big/ \sum_{i=1}^{k-1}(n_i d_i^3) - d_{k-1}\sum_{i=1}^{k-1}(n_i d_i)^2 \qquad \text{Eq 8}$$

The output average pellet diameter is given by

$$d_{AV}^{(o)} = \sum_{i=1}^{k-1} n_i d_i^{(o)} \Big/ \sum_{i=1}^{k-1} n_i \qquad \text{Eq 9}$$

Combining Equation 7 and Equation 9, the average output pellet diameter may be expressed in terms of the growth constant, γ.

$$d_{AV}^{(o)} = (1+\gamma)\left[\sum_{i=1}^{k-1}(n_i d_i) \Big/ \sum_{i=1}^{k-1} n_i\right] - \gamma d_{k-1} \qquad \text{Eq 10}$$

Equations 8 and 10 are combined and solved for $d_{AV}^{(o)}$, iteratively for k = m, m − 1 ,..., 1, until $d_{AV}^{(o)}$ is less than or equal to the average output diameter previously calculated by Equation 4. Then, for the sake of accuracy, the program goes back one class and crushes ball by ball within class k − 1. Now that the growth constant is known, the diameters of the remaining balls may be calculated according to Equation 7.

This output is then screened. Those balls which exceed the screen cut size become product, while the remainder are recycled as undersize, after renumbering.

4.2.3 Program Capabilities

The number of class sizes is limited to 120. The moisture content should be at least 7.9% if the bentonite content is 0%. A normal input would be W = 9.0%, B = 0.5%. The program output is sensitive to the number of seeds produced per increment, which is modified by the scaling factor, K_2. The amplitude of the output surge may be increased by increasing this factor. Also, the program is sensitive to moisture and bentonite variations. It should be calibrated for a given operation. For the example given, $K_1 = 8$ and $K_2 = 35$.

4.2.4 Data Inputs

Data input to the program is in free-field format (blanks or commas are used as separators). Input is read from logical file TAPE1.

Record 1: Operating parameters

DA	Static angle of repose of drum charge, (degrees)
DL	Drum length (m)
DR	Drum radius (m)
DSP	Drum rotational speed (r/min)
DSL	Drum slope (in./ft)
RHO	Feed density (t/m^3)

Record 2: Operating parameters

DN	Diameter of seed balls (m)
SC	Screen cutsize (m)
TMAX	Duration of simulation (min)
V	Feed rate (m^3/min)

Record 3: Initial recycle parameters

M	Number of size classes in initial recycle load, up to nine
D(I)	Diameter of size classes, up to nine classes

Record 4: Initial recycle parameters

N(I)	Number of balls in each size class, up to nine classes

Record 5: Feed parameters

W	Moisture content of feed (%)
B	Bentonite content of feed (%)

4.2.5 Printed Output

The output consists of three columns of numbers under the following headings: TIME (min), RECYCLE (% of feed), PRODUCT (% of feed).

4.3 SAMPLE RUN

A sample run is presented in the following pages. Computer plots are also shown in Figures 4.3 and 4.4, although the plots are not a program capability.

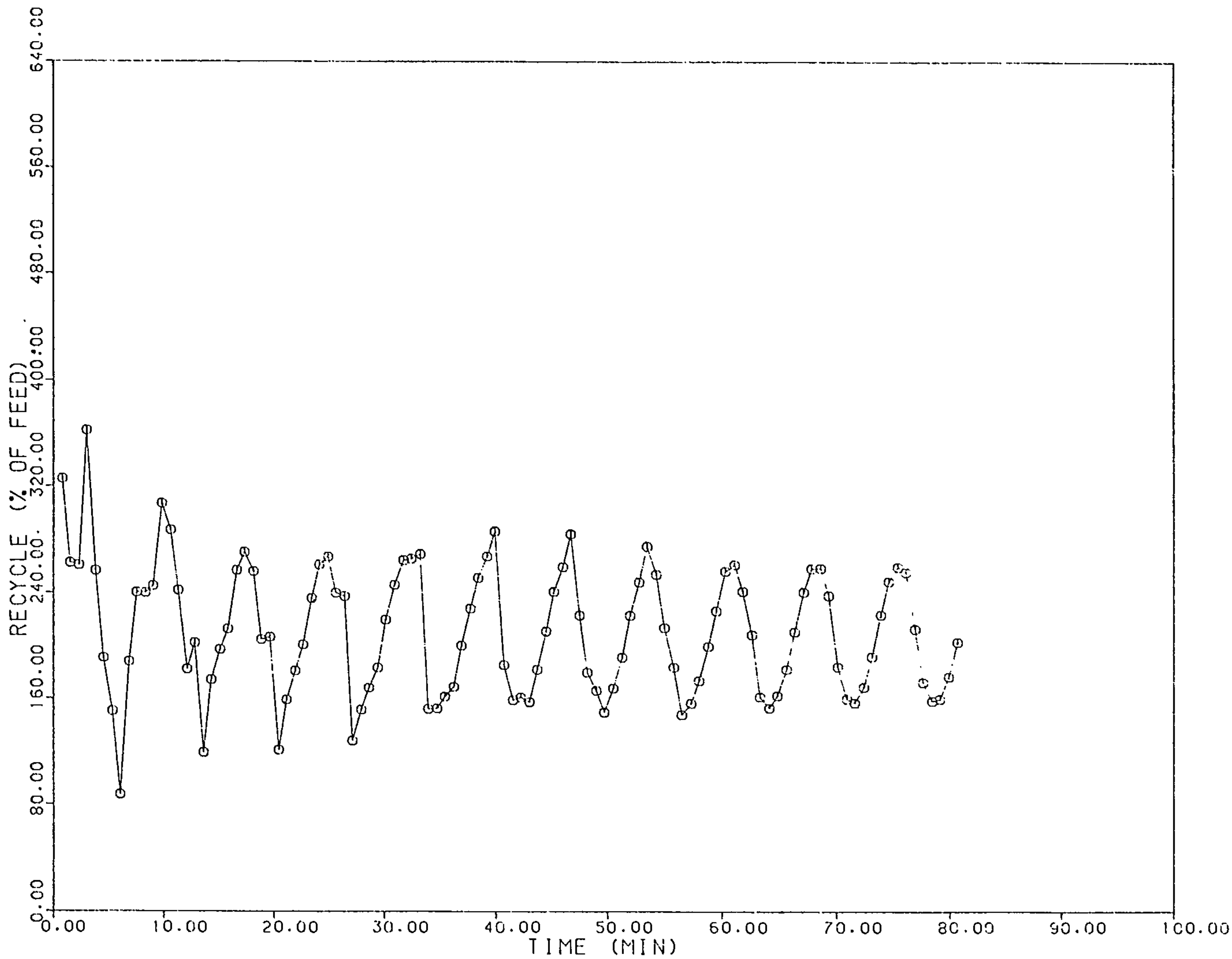


Fig. 4.3 — Plot of BALDRM output — recycle vs time

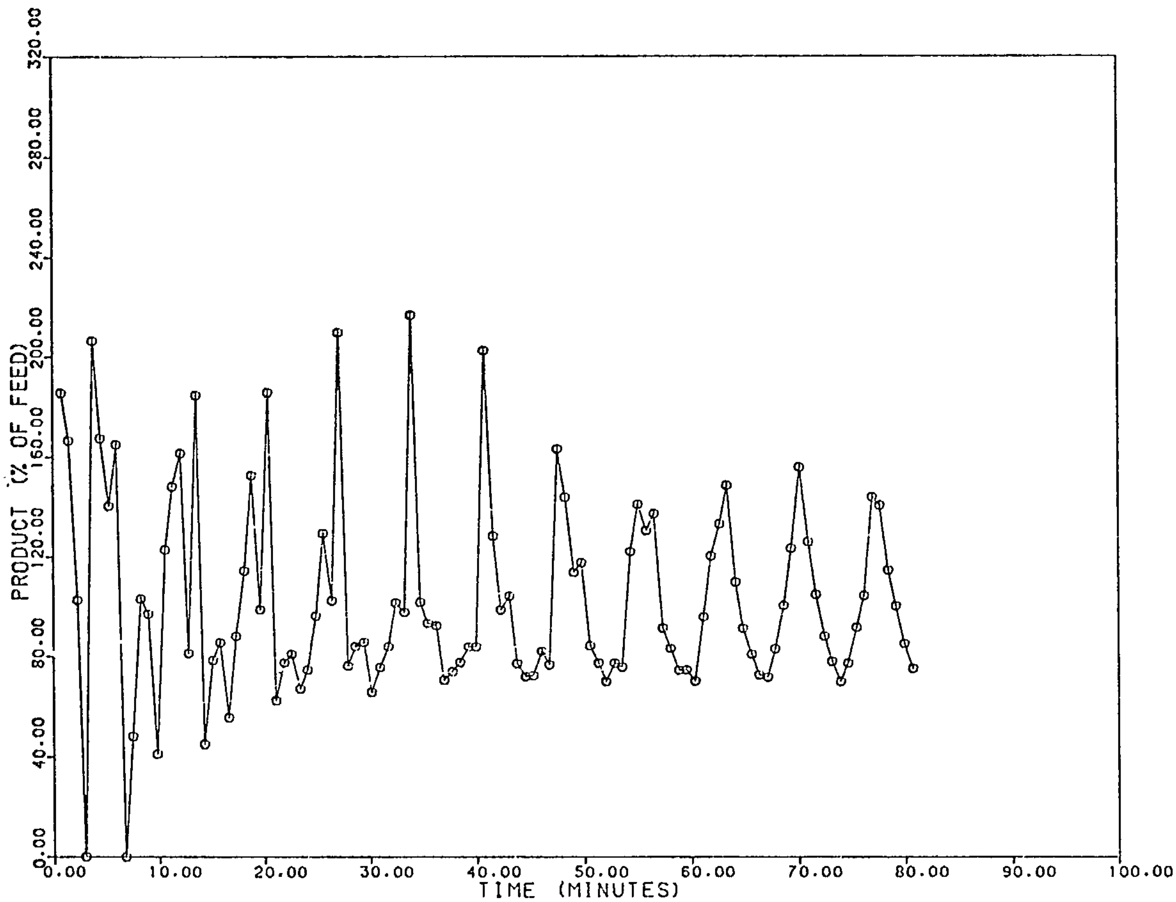


Fig. 4.4 — Plot of BALDRM output — product vs time

4.4 REFERENCES

1. Cross, M. "Mathematical model of balling-drum circuit of a pelletizing plant"; *Ironmaking and Steelmaking* 3:159-169; 1977.

2. Capes, C.E., and Danckwerts, P.V. "Granule formation by the agglomeration of damp powders, Part I: The mechanics of granule growth"; *Trans Inst Chem Eng* 43:116-124; 1965.

3. Capes, C.E., and Danckwerts, P.V. "Granule formation by the agglomeration of damp powders, Part 2: The distribution of granule sizes"; *Trans Inst Chem Eng* 43:125-130; 1965.

4. Sastry, K.V.S., and Fuerstenau, D.W. "Ballability index to quantify agglomerate growth by green pelletization"; *Trans Soc Min Eng Am Inst Min Metall Pet Eng* 252:254-258; 1972.

5. Ball, D.F.; Dartnell, J.; Davison, J.; Grieve, A.; and Wild, R. *Agglomeration of Iron Ores*; Heinemann Educational Books Ltd; London; 1973.

SIMULATION OF A BALLING DRUM (BALDRM)

PROGRAM DESCRIPTION: IN THIS MODEL BASED ON THE WORK OF M. CROSS, THE BALLING DRUM CIRCUIT OUTPUT IS DESCRIBED AS A FUNCTION OF TIME. THERE ARE TWO GROWTH MECHANISMS:

1. WITH FRESH FEED, NEW SEEDS ARE PRODUCED AND EXISTING BALLS GROW AT A RATE INDEPENDENT OF THEIR DIAMETER, WHILE THEIR RELATIVE SIZE DISTRIBUTION REMAINS CONSTANT.

2. IN THE ABSENCE OF FRESH FEED, BALL GROWTH TAKES PLACE BY THE CRUSHING OF THE SMALLEST BALLS PRESENT AND THE REDISTRIBUTION OF MATERIAL TO THE REMAINING BALLS IN PROPORTION TO THEIR DIAMETER.

THE FOLLOWING PARAMETERS ARE USED IN THE MODEL:

M	=	NUMBER OF SIZE CLASSES IN RECYCLE LOAD
D	=	VECTOR OF CLASS DIAMETERS (DIMENSIONED M)
N	=	VECTOR OF FREQUENCY DISTRIBUTION (DIMENSIONED M)
DA	=	STATIC ANGLE OF REPOSE OF DRUM CHARGE (DEG)
DL	=	DRUM LENGTH (M)
DR	=	DRUM RADIUS (M)
DSP	=	DRUM ROTATIONSL SPEED (RPM)
DSL	=	DRUM SLOPE (IN/FT)
RHO	=	FEED DENSITY (T/M3)
DN	=	DIAMETER OF SEED BALLS (M)
SC	=	SCREEN CUT SIZE (M)
TMAX	=	DURATION OF SIMULATION (MIN)
V	=	FEED RATE (M3/MIN)
W	=	FEED MOISTURE (%)
B	=	BENTONITE CONTENT IN FEED (%)

VALUES OF THESE PARAMETERS USED TO TEST THE MODEL ARE:

M	=	9
D	=	.009, .008, .007, .006, .005, .004, .003, .002, .1
N	=	6000, 6000, 4000, 7000, 6000, 5000, 6000, 3000, 2000
DA	=	25.
DL	=	11.
DR	=	1.85
DSP	=	11.
DSL	=	1.5
RHO	=	4.84
DN	=	.001
SC	=	.009
TMAX	=	80.
V	=	.3099
W	=	8.8
B	=	.5

TIME (MIN)	RECYCLE (% OF FEED)	PRODUCT (% OF FEED)
.8	325.735	185.702
1.5	262.242	166.699
2.3	260.575	102.758
3.0	362.249	0.000
3.8	256.499	206.473
4.5	190.809	167.617
5.3	150.647	140.553
6.0	87.456	165.082
6.8	187.998	0.000
7.5	240.253	48.381
8.3	240.033	103.238
9.0	245.182	97.231
9.8	307.053	41.241
10.6	286.940	122.994
11.3	241.830	148.315
12.1	182.289	161.649
12.8	202.290	81.304
13.6	119.173	184.772
14.3	174.216	45.154
15.1	197.256	78.563
15.8	212.730	85.587
16.6	256.777	55.711
17.3	270.205	88.171
18.1	255.856	114.509
18.8	204.707	152.776
19.6	206.537	98.909
20.4	121.079	185.803
21.1	158.934	62.431
21.9	180.938	77.607
22.6	200.719	80.953
23.4	235.876	67.108
24.1	260.934	74.701
24.9	266.839	96.375
25.6	239.797	129.436
26.4	237.264	102.532
27.1	128.174	209.826
27.9	151.565	76.299
28.6	168.134	84.025
29.4	183.244	85.791
30.1	219.618	65.765
30.9	245.851	75.658
31.7	264.183	83.968
32.4	265.273	101.586
33.2	268.745	97.858
33.9	152.192	216.766
34.7	152.636	101.849
35.4	161.507	93.345
36.2	168.843	92.450
36.9	200.086	70.584
37.7	227.992	73.946
38.4	251.129	77.640
39.2	267.026	83.819
39.9	285.769	83.926
40.7	185.272	202.515
41.5	158.802	128.403
42.2	160.927	98.802
43.0	157.375	104.323
43.7	181.895	77.143
44.5	210.989	72.034

45.2	240.677	72.420
46.0	259.189	82.128
46.7	283.759	76.691
47.5	223.037	163.244
48.2	179.679	143.947
49.0	166.104	113.862
49.7	149.741	117.749
50.5	167.836	84.245
51.3	191.274	77.384
52.0	222.859	70.022
52.8	247.958	77.344
53.5	274.588	75.772
54.3	253.659	122.133
55.0	213.608	141.047
55.8	183.634	130.579
56.5	147.907	137.333
57.3	156.370	91.351
58.0	173.584	83.203
58.8	199.524	74.472
59.5	226.241	74.562
60.3	256.020	70.132
61.1	260.847	95.847
61.8	241.090	120.387
62.6	208.366	133.098
63.3	161.281	148.681
64.1	153.092	109.854
64.8	162.203	91.207
65.6	182.096	80.825
66.3	210.516	72.578
67.1	240.564	71.722
67.8	257.978	83.013
68.6	258.320	100.416
69.3	237.870	123.377
70.1	184.039	155.974
70.9	159.894	125.967
71.6	156.852	104.861
72.4	168.758	88.027
73.1	191.797	77.945
73.9	223.451	69.911
74.6	248.519	77.293
75.4	259.189	91.589
76.1	255.306	104.415
76.9	212.751	143.979
77.6	172.314	140.686
78.4	158.197	114.590
79.1	159.704	100.249
79.9	176.497	84.997
80.7	202.844	75.108

```
STOP
025700 MAXIMUM EXECUTION FL.
13.505 CP SECONDS EXECUTION TIME.
```

5. ROTARY VACUUM FILTER (VACFIL)

5.1 PROGRAM IDENTIFICATION

Program Title:	Simulation of a Rotary **VAC**uum **FIL**ter.
Program Code Name:	VACFIL.
Authors:	W. Cameron, W.C. Feader.
Organization:	Energy, Mines and Resources, Canada Centre for Mineral and Energy Technology, Mineral Processing Laboratory.
Date:	July 1981.
Updates:	None.
Source Language:	CDC FORTRAN Extended 4.8 (American National Standard Institute FORTRAN X3.9 — 1966).
Availability:	Complete program listing is available from: CANMET, Energy, Mines and Resources, Technology Information Division, 555 Booth Street, Ottawa, Ontario, K1A 0G1.

Summary:

Program calculations:

1. Volume of filtrate in m^3/sec and metric tons/h.
2. Amount of filtercake in kg/m^2 and metric tons/h.
3. Moisture content of filtercake, initial and final %.
4. Cake thickness in metres and inches.
5. Re-calculates the per cent solids used as input.

Required data input:

1. Size of filter length (metres) and width (metres).
2. Revolutions of the drum per minute.
3. The angle subtended from the centre of the drum to points of immersion in degrees.
4. Gauge pressure or vacuum inside filter, in N/m^2, (Newtons per square metre).
5. Size distribution of filter feed (cumulative % retained).
6. Weight fraction of solids in filter feed.
7. Density of the suspending medium in kg/m^3. (Unless otherwise specified, the program assumes the density of the suspending medium to be that of water.)
8. Density of solids in kg/m^3.
9. Porosity of filtercake expressed as a fraction.

5.2 ENGINEERING DOCUMENTATION

5.2.1 Narrative Description

Most mineral processing plants face the problem of having to process large quantities of suspensions, which occur as intermediate products in the course of a production operation. Frequently, the process takes the form of separating the suspension into the respective solid and liquid components. Rotary vacuum filters can be used advantageously wherever large quantities of slurries require filtration. Figure 5.1 is a general view of a rotary vacuum filter.

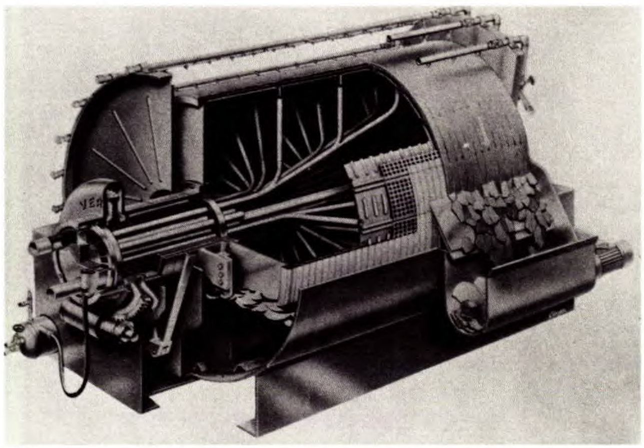


Fig. 5.1 — Exploded view of a rotary drum filter (Courtesy Filters Vernay)

A rotary filter machine is usually one link in a chain of production stages. It is therefore necessary to operate the filter in such a way that the desired operating goal is attained in each case. The target may be to process a certain quantity of slurry, to maintain a certain level of moisture content in the filtercake, and usually to achieve a certain (generally as small as possible) solids content in the filtrate. A mathematical model of a rotary vacuum filter is a system of equations which contains the various operating parameters such as speed of rotation and pressure, etc. as variables. Although this is a very basic version, it is expected that various options will be added to the program in future versions to make it more flexible.

Nomenclature

A, A_F	[m^2]	total and the equivalent filter area submerged in the suspension
C	[kg/kgl]	turbidity concentration
c	[m]	circumference of drum
d	[μm]	grain size
f_k	[kgl/kg]	moisture content of filtercake
f_{ko}	[kgl/kg]	initial moisture of cake
G	[kg/m sec]	amount of filtercake
H	[m]	filtercake thickness
θ	[deg]	angle subtended by immersed portion of filter
I	[m]	immersed portion of the drum circumference
L	[m]	diameter of drum
l		liquid
M	[kg/s]	amount of turbidity of suspension
n	[1/s]	No. of rotations of the filter drum
P, P_k	[N/m^2]	filtration pressure or fall of pressure at the filtercake
P_F	[N/m^2]	fall in pressure at the filtration equipment
P_{kn}	[N/m^2]	capillary pressure
P_{TR}	[N/m^2]	vacuum in the drying zone
s		solid
S	[%]	per cent solids
V	[m^3/sec]	amount of filtrate
W	[m]	width of drum
α	[$1/m^2$]	specific filter resistance (calculated on unit volume of filtered solid)
α_k	[$1/m^2$]	specific filter resistance (calculated on unit volume of filtercake)
ϵ	[m/m^3]	porosity of the filtercake
η	[kg/ms]	viscosity
ρ_1	[kg/m^3]	density of the suspending medium
ρ_s	[kg/m^3]	density of the solids suspension.

5.2.2 Method of Solution

5.2.2.1 Input (Example)

The model is illustrated by a detailed calculation of the various model equations for a filter with the following characteristics:

Dimensions:	length 1.82 m, diameter 1.82 m
Speed:	0.8 rpm
Angle of immersion:	120 degrees
Gauge reading:	26 inches of Hg = $3.386 \times 10^{-3} \times 26 = 8.805 \times 10^{+4}$ N/m^2
Fraction of solids in feed:	0.6 by weight
Density of suspending medium:	1000 kg/m^3
Density of solid:	2300 kg/m^3 (brick dust)
Porosity of filtercake:	0.25

The size distribution of the feed is also provided.

5.2.2.2 Calculations

Calculate circumference of the drum (c) (by Eq 1)

$$c = \pi L \qquad \text{Eq 1}$$
$$= 3.14 \times 1.82$$
$$= 5.71 \text{ m}$$

Calculate the area of the drum (A) (by Eq 2)

$$A = c\,W \qquad \text{Eq 2}$$
$$= 5.71 \text{ m} \times 1.82 \text{ m}$$
$$= 10.40 \text{ m}^2$$

Calculate** I**, the immersed portion of the circumference (by Eq 3)

$$I = \frac{2\,\pi\, r}{360}\,\theta$$
$$= \frac{2 \times 3.14 \times .91}{360}\,120 = 1.90 \text{ m} \qquad \text{Eq 3}$$

where: r = radius of the drum

Calculate A_F, the immersed area of the drum (by Eq 4)

$$A_F = I\,W \qquad \text{Eq 4}$$
$$= 1.90 \times 1.82$$
$$= 3.46 \text{ m}^2$$

Calculate the time of cake formation (by Eq 5)

$$t = A_F/(A\,n) \qquad \text{Eq 5}$$
$$= 3.46/10.4 \times 0.8$$
$$= 0.42 \text{ min}^* \times 60 = 24.94 \text{ sec}$$

Calculate the total specific filtercake resistance from the grain size distribution ($1/m^2$)

The following magnitudes are ascertained from the grain size distribution curve or the total cumulative per cent retained curve:

The individual resistance of fractions according to Equation 6:

$$\alpha_1 = 2300/d^2 \qquad \text{Eq 6}$$

Fine-grained portion of the particular fraction is expressed by the relationship

$$\frac{\text{Amount of fine fraction}}{\text{total amount}} = \frac{R(j) - R(j-1)}{R(j)} \qquad \text{Eq 7}$$

wherein R(j) denotes the total per cent retained for the jth fraction.

Proportionality of the grain sizes of the fine fraction to the grain sizes of the coarse fractions, or to the average grain size of the mixture:

$d_j/(d_j/2)$ with even j

$d_j/d(j+1/2)$ with odd j. Eq 8

One starts in the case of a step-wise calculation of the total resistance with the coarsest fraction from Equation 6. The calculation is successively continued through

$$\alpha'_j = (\alpha'_{j-1})^{1-M_j}\,\alpha_j^{M_j} \qquad \text{Eq 9}$$

with

$$M_j = \frac{R_j - (R_j - R_{j-1})/R_j}{0.85[d_j/(d_j/2)]^2 + 0.15} \quad \text{when j, the element number, is even}$$

$$M_j = \frac{R_j - (R_j - R_{j-1})/R_j}{0.85[d_j/(d_{j+1}/2)]^2 + 0.15} \quad \text{when j, the element number, is odd} \qquad \text{Eq 10}$$

0.85 and 0.15 are parameters experimentally determined for very fine material. For coarser material these parameters will change. j assumes all values from 2 to n, when n is the number of fractions into which the entire size distribution was divided. The values R_j and d_j can be obtained from the total per cent retained curve from a granulation analysis. α'_n is then the needed filtercake resistance of the entire size distribution.

The following data and example will illustrate the use of these equations.

	Size μm	***Cum % retained***
1.	37	4.0
2.	26	8.0
3.	18	17.0
4.	13	28.0
5.	9	39.0
6.	6.5	58.0
7.	4.5	72.0
8.	3.2	86.0
9.	2.2	97.0
10.	1.6	100.0

Calculation of specific cake resistance

Using Equation 10

1) $M_2 = \dfrac{[8.0 - (8.0 - 4.0)]/8.0}{0.85[26/(26/2)]^2 + 0.15} = 0.141$

2) $M_3 = \dfrac{[17.0 - (17.0 - 8.0)]/17.0}{0.85[18.0/(13/2)]^2 + 0.15} = 0.079$

3) $M_4 = \dfrac{[28.0 - (28.0 - 17.0)]/28.0}{0.85[13.0/(13/2)]^2 + 0.15} = 0.111$

4) $M_5 = \dfrac{[39.0 - (39.0 - 28.0)]/39.0}{0.85[9.0/(6.5/2)]^2 + 0.15} = .0423$

5) $M_6 = \dfrac{[58.0 - (58.0 - 39.0)]/58.0}{0.85[6.5/(6.5/2)]^2 + 0.15} = 0.092$

6) $M_7 = \dfrac{[72.0 - (72.0 - 58.0)]/72.0}{0.85[4.5/(3.2/2)]^2 + 0.15} = 0.028$

7) $M_8 = \dfrac{[86.0 - (86.0 - 72.0)]/86.0}{0.85[3.2/(3.2/2)]^2 + 0.15} = 0.046$

8) $M_9 = \dfrac{[97.0 - (97.0 - 86.0)]/97.0}{0.85[2.2/(1.6/2)]^2 + 0.15} = 0.017$

9) $M_{10} = \dfrac{[100.0 - (100.0 - 97.0)]/100.0}{0.85[1.6/(1.6/2)]^2 + 0.15} = 0.008$

If n had been an odd number, d_{j+1} would be the next smaller size in a root 2 series. In the above case, if the last size fraction 1.6 μm had been an odd number, d_{j+1} would have been $1.6\sqrt{2}$, i.e., 1.13.

Substituting the previously determined M values in Equation 9 and starting with Equation 6

1) 37 μm
$\alpha'_1 = 2300/(37)^2 = 1.680$

2) 26 μm
$\alpha'_2 = (1.680)^{0.859} \times [2300/(26)]^{0.141} = 1.856$

3) 18 μm
$\alpha'_3 = (1.856)^{.921} \times (7.099)^{0.079} = 2.063$

4) 13 μm
$\alpha'_4 = (2.063)^{0.889} \times (13.609)^{0.111} = 2.544$

5) 9 μm
$\alpha'_5 = (2.544)^{0.958} \times (28.395)^{0.0423} = 2.815$

6) 6.5 μm
$\alpha'_6 = (2.815)^{0.908} \times (54.438)^{0.092} = 3.697$

7) 4.5 μm
$\alpha'_7 = (3.697)^{0.972} \times (113.580)^{0.028} = 4.069$

8) 3.2 μm
$\alpha'_8 = (4.069)^{0.954} \times (224.609)^{0.046} = 4.894$

9) 2.2 μm
$\alpha'_9 = (4.894)^{0.983} \times (475.207)^{0.017} = 5.290$

10) 1.6 μm
$\alpha'_{10} = (5.290)^{0.992} \times (898.438)^{0.008}$
$= 5.511697939/\mu m^2$

Therefore, the specific filtercake resistance is $\alpha = 5.512 \times 10^{12}/m^2$. The units $1/\mu m^2$ are derived from the relationship established by the pore surface. One should expect a proportionality between cake resistance α and the reciprocal pore surface, as a comparison between the laws of Hagen and Poiseuille and of Darcy:

i.e., $\alpha \sim 1/r^2 \sim 1/d^2$

Since $1/m^2 = 1/(10^{-6})^2\ \mu m^2$ then

$$\alpha = 5.512 \times 10^{12}/m^2 \qquad \text{Eq 11}$$

Calculation of capillary pressure (N/m²)

The Laplace equation is valid for the ascent of fluids in narrow tubes.

$$hs = \frac{2\,\sigma \cos\theta}{\rho_1\, g\, r} \qquad \text{Eq 12}$$

Here σ is the surface tension of the liquid, θ is the boundary angle (assume $\cos\theta = 1$ for water), and hs the vertical capillary height. Since, on one hand, there exists proportionality for the capillary pressure P_{kn}, then

$$P_{kn} = hs\, \rho_1 g \sim 1/r \qquad \text{Eq 13}$$

On the other hand, according to Equation 11, $\alpha \sim 1/r^2$, it may then be assumed that there exists the following relationship between the capillary pressure P_{kn} and the filtercake resistance α.

$$P_{kn} = K_3\, 2\, \sigma \cos\theta\, \alpha^{0.5} \qquad \text{Eq 14}$$

where: K_3 = 0.063 for fully wetted particles
σ = 72.9×10^{-3} N/m for water
$\cos\theta$ = 1 for water
α = $5.512 \times 10^{12}/m^2$ as previously determined.

To determine the units for P_{kn}, substitute units in Equation 14:

$$P_{kn} = 1 \cdot \frac{N}{m} \cdot \left(\frac{1}{m^2}\right)^{0.5} = N/m^2$$

Substituting known values in Equation 14

$$P_{kn} = 0.063 \times 2(72.9 \times 10^{-3}) \times 1 \times (5.512 \times 10^{12})^{0.5} = 2.157 \times 10^4\ N/m^2$$

Initial moisture in filtercake (kgl/kgs)

The following relationship has been determined experimentally:

$$f_{ko} = 0.72\, \frac{\rho_1}{\rho_s}\, \frac{\epsilon}{1-\epsilon} \qquad \text{Eq 15}$$

$\rho_1 = 1000\ kg/m^3$

$\rho_s = 2300\ kg/m^3$

$\epsilon = 0.25$

Substituting known values in Equation 15

$$f_{ko} = 0.72 \cdot \frac{1000}{2300} \cdot \frac{.25}{.75} = 0.104$$

$N/m^2 \div N/m^2$ gives a dimensionless answer. To convert to per cent multiply by 100, then:

$$f_{ko} = 0.104 \times 100 = 10.4\%$$

Moisture content of filtercake (dimensionless)

For the range $P_{TR} > P_{kn}$, the empirical function which follows is valid:

$$f_k/f_{ko} = 1/3 - 1/3 \log [(PT_r/p_{kn})\text{-}0.99] \qquad \text{Eq 16}$$

$f_{ko} = 0.104$

$P_{TR} = 8.805 \times 10^4\ N/m^2$

$P_{kn} = 2.157 \times 10^4\ N/m^2$

Units are determined by

$$\frac{N/m^2}{N/m^2} = 1$$

Solving Equation 16 then gives

$$f_k = 0.104\,\{1/3 - 1/3 \log [(8.805 \times 10^4/2.157 \times 10^4) - 0.99]\} = 1.767 \times 10^{-2} \text{ i.e., } .01767$$

To express the answer as per cent moisture, multiply by 100

$$f_k = 0.01767 \times 100 = 1.77\%$$

Pressure drop across the filtercake

The entire filtration pressure P, consists of the pressure drop at the filtercake P_k (in the case = P_{TR}) and the very much smaller loss in the equipment P_F

$$P = P_k + P_F$$

$$P_K = 8.805 \times 10^4 \text{ N/m}^2$$

$$P_F = 3.386 \times 10^3 \text{ N/m}^3$$

$$= 1 \text{ in. Hg and is an assumption}$$

Solving Equation 17 then gives

$$P = 8.805 \times 10^4 + 3.386 \times 10^3$$

$$= 9.144 \times 10^4 \text{ N/m}^2$$

Amount of filtrate (m³/sec)

The following equation is used to determine the amount of filtrate:

$$V^2 = \frac{2A^2(P - p_F)(1 - \epsilon)\rho_s t}{\alpha_k\ \eta\ \rho_1\ C} \qquad \text{Eq 18}$$

η = viscosity of water (by default)

= 1 centipoise

= 1 gm/cm sec

= 0.001 kg/m sec

From input and previous calculations we know:

$A = 10.4 \text{ m}^2$

$P = 9.144 \times 10^4 \text{ N/m}^2$ i.e. $^*9.324 \times 10^3 \text{ kg m/sec}^2\text{m}^2$

$PF = 3.386 \times 10^3 \text{ N/m}^2$ i.e. $^*3.453 \times 10^2 \text{ kg m/sec}^2\text{m}^2$

$1\text{-}\epsilon = 0.75$

$\rho_s = 2300 \text{ kg/m}^3$

$\rho_1 = 1000 \text{ kg/m}^3$

$t = 24.94 \text{ secs}$

$\alpha = 5.512 \times 10^{12}\text{/m}^2$

$\alpha_K = \alpha(1 - \epsilon) = 4.134 \times 10^{12}\text{/m}^2$

$\eta = 0.1 \text{ kg/m.sec}$

$C = 0.6/0.4 = 1.500$

*1 N/m = 9.80665 kg m/sec²m².

To determine the units for V^2, substitute the units for each variable in Equation 18:

$$V^2 = \frac{\frac{m^4}{1} \cdot \frac{kgm}{sec^2 m^2} \cdot 1 \cdot \frac{kg}{m^3} \cdot \frac{sec}{1}}{\frac{1}{m^2} \cdot \frac{kg}{m.sec} \cdot \frac{kg}{m^3} \cdot 1 \cdot 1}$$

$$= \frac{m^6}{1} \cdot \frac{kg\ m^2sec}{kg\ m^2sec} \cdot \frac{m^3}{kg} \cdot \frac{kg}{m^3} \cdot \frac{1}{sec} = \frac{m^6}{sec^2}$$

and V = m³/sec

Substituting values in Equation 18

$$V^2 = \frac{2(10.4)^2\,(9.324 \times 10^3 - 3.453 \times 10^2) \times 0.75 \times 2300 \times 24.94}{4.134 \times 10^{12} \times 0.1 \times 1000 \times 1.500}$$

$$= 1.347516068 \times 10^{-4}$$

$$V = 1.160825598 \times 10^{-2} \text{ m}^3\text{/sec}$$

As an option, one may express the volume of filtrate in metric tons/h. To convert V into metric tons per hour

10^{-3} m³/sec = 11.60825598 kg/sec

11.60825598 kg/sec × 3600 = 4.178972153 × 10^4 kg/h

4.178972153 × 10^4 kg/h × 0.001 = 41.78972153 metric tons/h

Quantity of filtercake (kg/m²/sec)

Considering the residual moisture in the filtercake, Equation 19 is used to determine the amount of filtercake

$$G = \frac{V}{A} \cdot \frac{\rho_1\ C}{1 - (f_k \cdot C)} \qquad \text{Eq 19}$$

From previous calculations we know

$V = 1.160825598 \times 10^{-2} \text{ m}^3\text{/sec}$

$A = 10.4 \text{ m}^2$

$\rho_1 = 1000 \text{ kg/m}^3$

$C = 1.500$

$f_k = 1.767 \times 10^{-2}$

To determine the units for G, substitute the units for each variable in Equation 19:

$$G = \frac{\frac{m^3}{sec} \cdot \frac{kg}{m^3} \cdot 1}{\frac{m^2}{1} \cdot 1} = \frac{m^3 kg}{m^5 sec} = \text{kg/m}^2\text{sec}$$

Substituting the above values in Equation 19

$$G = \frac{1.160825598 \times 10^{-2}}{10.4} \times \frac{1000 \times 1.500}{1-(1.767 \times 10^{-2} \times 1.500)}$$
$$= 1.719852377 \text{ kg/m}^2 \text{ sec}$$

As an option, we may give the quantity of filtercake in metric tons per hour. To convert 1.719852377 kg/m²sec into metric tons/h

$$1.719852377 \times 3600 = 6.191468557 \times 10^3 \text{ kg/m}^2 \text{ h}$$

$$6.191468557 \times 10^3 \times 0.001 = 6.191468557 \text{ metric tons/m}^2 \text{ h}$$

Since the area of the drum is 10.40 m², then 6.191468557 × 10.40 = 64.39127299 metric tons/h.

Per cent solids in slurry

As a means of checking if volume of filtrate and quantity of filtercake are correct (i.e., proportionately so), back calculate the per cent solids using the calculated data and the following data:

$$\% S = \frac{G}{(G + V)} \times 100 \qquad \text{Eq 20}$$

$V = 4.178972153 \times 10$ metric tons/h

$G = 6.439127299 \times 10$ metric tons/h

$V+G = 10.61809945 \times 10$ metric tons/h

$$\% S = \frac{6.439127299 \times 10}{10.61809945 \times 10} = 60.64\%$$

Thickness of filtercake (m)

Cake thickness may be calculated by Equation 21:

$$H = \frac{V \rho_1 C}{(1-\epsilon)\rho_s A} \qquad \text{Eq 21}$$

From input and previous calculation we know

$V = 1.160825598 \times 10^{-2}$ m³/sec

$\rho_1 = 1000$ kg/m³

$\rho_s = 2300$ kg/m³

$C = 1.500$

$1\text{-}\epsilon = 0.75$

$A = 10.40$ m²

Determine the correct units for H:

$$H = \frac{\frac{m^3}{sec} \cdot \frac{kg}{m^3} \cdot 1}{1 \cdot \frac{kg}{m^3} \cdot \frac{m^3}{1}} = \frac{m^3}{sec} \cdot \frac{kg\ m^3}{kg\ m^3} \cdot \frac{1}{m^2} = m/sec$$

The drum turns 0.8 rev/60 sec or 1 rev every 60/0.8 = 75 sec.

$$H = \frac{1.160825598 \times 10^{-2} \times 1000 \times 1.500}{0.75 \times 2300 \times 10.4}$$
$$= 9.705899647 \times 10^{-4} \text{ m/sec}$$

Cake thickness then is $9.705899649 \times 10^{-4} \times 75 = 0.072794247$ m.

For convenience we may report this in inches:

$$.072794247 \times 39.37 = 2.87 \text{ in.}$$

5.2.2.3 Output

1. Volume of filtrate = 1.161×10^{-2} m³/sec or 41.790 metric tons/h.
2. Amount of filtercake = 1.720 kg/m³/sec or 64.391 metric tons/h.
3. Moisture content of filtercake = 1.77%.
4. Cake thickness = 0.006 m or 2.87 inches.
5. Recalculated % solids = 60.64%.

5.2.3 Program Capabilities

The program requires the input listed below and is confined to very fine particle size distributions, e.g., top size approximately 400 mesh. However, a new version should enable coarser size distribution to be used and be more flexible in input-output parameters.

The program arrays, 'SIZDIST' and 'CAKRES' are set to handle 20 size fractions in the filter feed size distribution. The size of these arrays must be set at NFRACT+1 (number of size fractions plus one) when redimensioning.

5.3 SAMPLE RUN

A typical sample run is presented in the following pages.

SIMULATION OF A ROTARY VACUUM FILTER (VACFIL)

PROGRAM DESCRIPTION: THIS MODEL IS BASED ON THE WORK OF H.RUDOLF. USING THE OPERATIONAL PARAMETERS OF A FILTER UNIT: WIDTH, HEIGHT, ROTATION, SPEED, ANGLE SUBTENDED, GAUGE PRESSURE, PERCENT SOLIDS IN THE FEED SLURRY AND SIZE DISTRIBUTION OF THE FEED, AN ESTIMATE OF THE UNIT THROUGHPUT AND FILTER CAKE COMPOSITION IS OBTAINED.

THE FOLLOWING PARAMETERS ARE USED IN THE MODEL:

```
NFRACT  = NUMBER OF SIZE FRACTIONS
FLEN    = FILTER LENGTH
FWID    = FILTER WIDTH
RPM     = ROTATION SPEED OF DRUM
ANGLS   = ANGLE SUBTENDED FROM CENTRE OF DRUM
DENMED  = DENSITY OF SUSPENDING MEDIUM
DENSOL  = DENSITY OF SOLIDS
PORCAK  = POROSITY OF FILTER CAKE
SIZDIST = SIZE DISTRIBUTION OF THE FEED (A 2-DIMENSIONAL ARRAY,
          THE FIRST ELEMENT = THE SIZE IN MICRONS;  THE
          SECOND = CUMULATIVE % PASSING FOR EACH SIZE)
GPRESS  = GAUGE PRESSURE (IN-HG)
PERSOL  = PERCENT SOLIDS IN FEED
```

VALUES OF THESE PARAMETERS USED TO TEST THE MODEL ARE:

```
NFRACT  = 10
FLEN    = 1.82
FWID    = 1.82
RPM     = 0.8
ANGLS   = 120
DENMED  = 1000
DENSOL  = 2300
PORCAK  = 0.25
(SIZDIST(I,1),I=1,NFRACT) =37, 26, 18, 13, 9,
                           6.5, 4.5, 3.2, 2.2, 1.6
(SIZDIST(I,2),I=1,NFRACT) =4.0, 8.0, 17.0, 28.0, 39,
                           58, 72, 86, 97, 100
```

```
ENTER GAUGE PRESSURE (IN\HG )
7.9E+04 < GPRESS < 9.7E+04 , GPRESS=88050.0

ENTER PERCENT SOLIDS IN THE FEED
55 < PERSOL < 65              PERSOL=60.0
```

ROTARY VACUUM FILTER SIMULATION RESULTS

UNIT DESCRIPTION:

WIDTH	HEIGHT	AREA	CIRCUMFERENCE	IMMERSED AREA	RPM'S
1.8 (M)	1.8 (M)	10.4 (M**2)	5.7 (M)	3.5 (M**2)	.8

GAUGE PRESSURE	ANGLE SUBTENDED	% SOLIDS IN FEED	DENSITY OF SOLIDS	DENSITY OF LIQUID	POROSITY OF FILTERCAKE
88050.0	120.0	60.0	2300.0	1000.0	.25

FEED SLURRY - SIZE DISTRIBUTION FOR 10 FRACTIONS

SIZE (MICRONS)	37.0	26.0	18.0	13.0	9.0	6.5	4.5	3.2	2.2	1.6
CUMULATIVE % RETAINED	4.0	8.0	17.0	28.0	39.0	58.0	72.0	86.0	97.0	100.0
SIZE (MICRONS)	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CUMULATIVE % RETAINED	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

VOLUMES:

FILTRATE	.116014E-01	(M**3/SEC)	FILTER	1.71804	(KG/M**2 SEC)
	41.7650	(TONNES/H)	CAKE	64.3617	(TONNES/H)

MOISTURE CONTENT OF FILTERCAKE (%) CAKE THICKNESS (M AND INCHES)

INITIAL 10.4348 FINAL 1.77558 .727078E-01 2.86251

CALCULATED % SOLIDS	TIME OF CAKE FORMATION	PRESSURE DROP (N/M**2)	CAPILLIARY PRESSURE (N/M**2)
60.6	25.0 (SEC)	91436.0	21616.6

STOP
026500 MAXIMUM EXECUTION FL.
0.391 CP SECONDS EXECUTION TIME.

6. MIXER2 AND MIXER3

6.1 PROGRAM IDENTIFICATION

Program Title:	**MIXER** of **2** or **3** streams.
Program Code Names:	MIXER2 and MIXER3.
Author:	F. Flament.
Organization:	Energy, Mines and Resources, Canada Centre for Mineral and Energy Technology, Mineral Processing Laboratory.
Date:	May 1985.
Updates:	July 1985.
Source Language:	CDC FORTRAN Extended 4.8 (American National Standard Institute FORTRAN X3.9 — 1966).
Availability:	Complete program listing is available from: CANMET, Energy, Mines and Resources, Technology Information Division, 555 Booth Street, Ottawa, Ontario, K1A 0G1.

6.2 ENGINEERING DOCUMENTATION

6.2.1 Narrative Description

A mixer is a very common and trivial unit in all mineral processing plants. It materializes a water addition point on the junction of several streams in a sump box. The two subroutines proposed here (MIXER2 and MIXER3) permit the simulation of 2- or 3-stream junctions (including water addition streams). The model used is a static one, which means that mixing conditions are not taken into account.

6.2.2 Method of Solution

The mixing of 2 or 3 streams is simulated by a trivial addition, component by component, of the feed streams to the unit. The components involved are the solid and water flow rates and the size distributions. The particle size distributions may be expressed in weight fractions, weight percentages or weights. If a specific gravity distribution is known, a size distribution per specific gravity or a specific gravity distribution per size interval can be used. The characteristics of the resulting product keep the same units as those used for the feed streams.

The following equations, where upper case letters refer to flow rates and lower case letters to assays, represent the model used:

in MIXER2:

$$S = S_1 + S_2 \qquad \text{Eq 1}$$

$$W = W_1 + W_2 \qquad \text{Eq 2}$$

$$s(i,j) = \left[s_1'(i,j) + s_2'(i,j) \right] / s' \qquad \text{Eq 3}$$

in MIXER3:

$$S = S_1 + S_2 + S_3 \qquad \text{Eq 4}$$

$$W = W_1 + W_2 + W_3 \qquad \text{Eq 5}$$

$$s(i,j) = \left[s_1'(i,j) + s_2'(i,j) + s_3'(i,j) \right] / s' \qquad \text{Eq 6}$$

where: S or s refer to solid

W refers to water

i,j refers to size and/or specific gravity interval.

In Equations 3 and 6, s', s_1', s_2', and s_3' are equal to s, s_1, s_2, and s_3 if feed size distributions are in weight fractions or percentages, or equal to 1 if feed size distributions are weights.

6.3 SAMPLE RUN

Since MIXER2 and MIXER3 are only utilities for the simulation executives, the reader is referred to Chapter 6 of the SPOC Manual for examples.

7. EXTRAPOLATION (EXTRAP)

7.1 PROGRAM IDENTIFICATION

Program Title:	**EXTRAP**olation of size distributions.
Program Code Name:	EXTRAP.
Author:	F. Flament.
Organization:	Energy, Mines and Resources, Canada Centre for Mineral and Energy Technology, Mineral Processing Laboratory.
Date:	July 1985.
Updates:	None.
Source Language:	CDC FORTRAN Extended 4.8 (American National Standard Institute FORTRAN X3.9 — 1966).
Availability:	Complete program listing is available from: CANMET, Energy, Mines and Resources, Technology Information Division, 555 Booth Street, Ottawa, Ontario, K1A 0G1.

7.2 ENGINEERING DOCUMENTATION

7.2.1 Narrative Description

EXTRAP is a utility subroutine proposed to avoid the manipulation of useless zeroes in the simulation of grinding plants. For instance, in a typical three-stage grinding plant, the size distribution of the overflow of the secondary cyclone does not generally require the usage of the coarsest size intervals to characterize the feed stream to the rod mill. At the other end of the size distributions, while fines are not looked at in the plant feed stream, they become very important for a good simulation of the behaviour of the secondary cyclones.

Generally, zero values appear at the bottom of the feed stream size distribution and at the top of the cyclone overflow size distribution. Those zeroes are useless and increase the memory requirements and execution time. To avoid this, EXTRAP simulates a shift in the range of size intervals.

7.2.2 Method of Solution

The subroutine EXTRAP does two things at the same time on a stream size distribution. It cuts away the number of coarse size intervals requested by its user, and extrapolates the size distribution in the fine direction by an equal number of size intervals, i.e., the total number of sieves used is kept the same, but the size range is different.

The model used to perform the extrapolation supposes that the cumulative size distribution versus the size interval's upper dimensions is linear in the fine range on a log-log scale.

EXTRAP fits a straight line through the four smallest size intervals of the size distribution. The best linear parameter values are those which minimize a least square criterion. Then the linear model is used to extrapolate the size distribution by the requested number of size intervals. The model is limited to an extrapolation of up to four new size intervals. Furthermore, to be extrapolated, a size distribution should have at least eight non-zero values.

7.3 SAMPLE RUN

Since EXTRAP is only a utility subroutine, no sample run is presented here. The user is referred to Chapter 6 of the SPOC Manual where it is applied in the grinding plant simulator.