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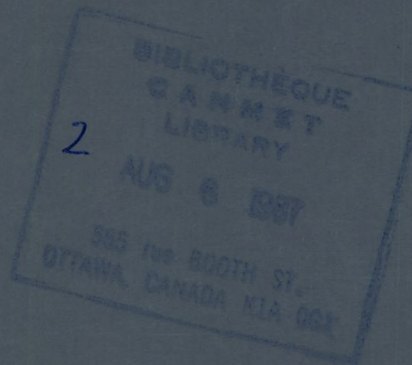
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SPOC

Simulated Processing of Ore and Coal



Chapter 7 Model Calibration



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The **SPOC** Manual

Chapter 7 Model Calibration Model Calibration for Mineral Processing Simulation

D. Laguitton and F. Flament

Editor: D. Laguitton

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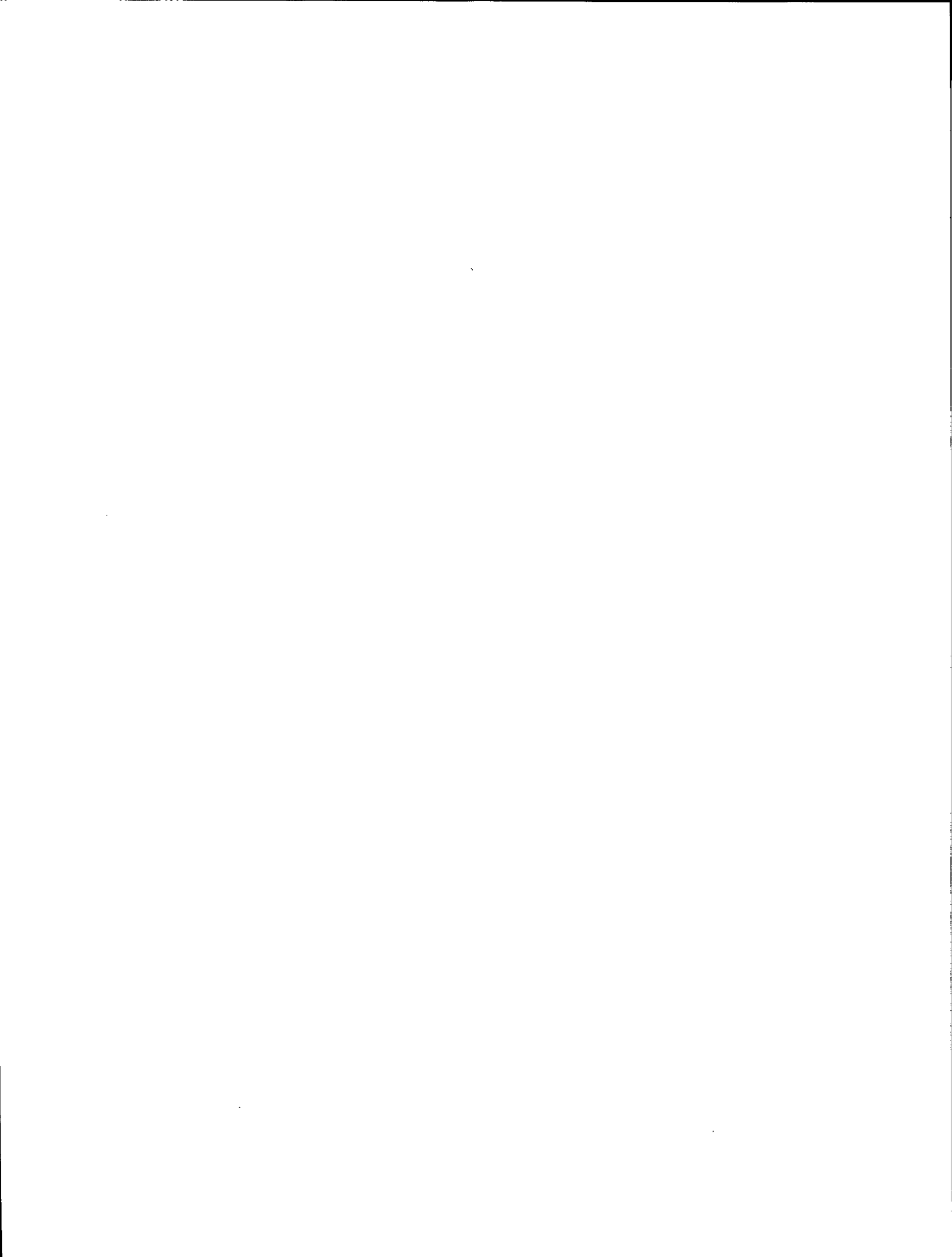
THE SPOC MANUAL

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

These chapters are available from: CANMET, Energy, Mines and Resources Canada
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555 Booth Street
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.

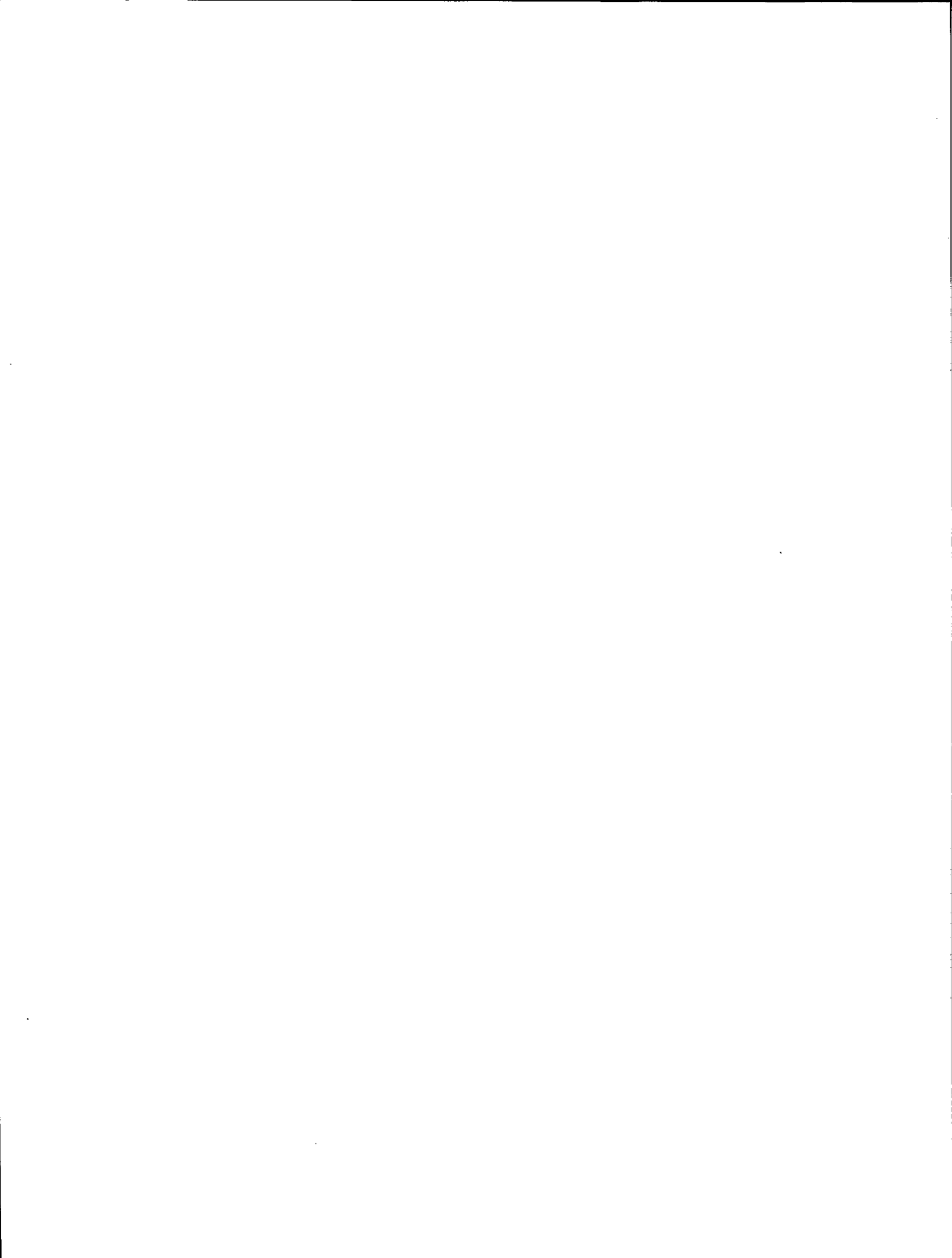
D. Laguitton
SPOC Project Leader
Canada Centre for Mineral and Energy Technology

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

Phenomenological or empirical models used to describe most mineral and coal process units require extensive calibrations at the development stage as well as for any subsequent update. The range of techniques required for such calibrations goes from simple linear regression to computation-intensive, multivariable non-linear model calibrations.

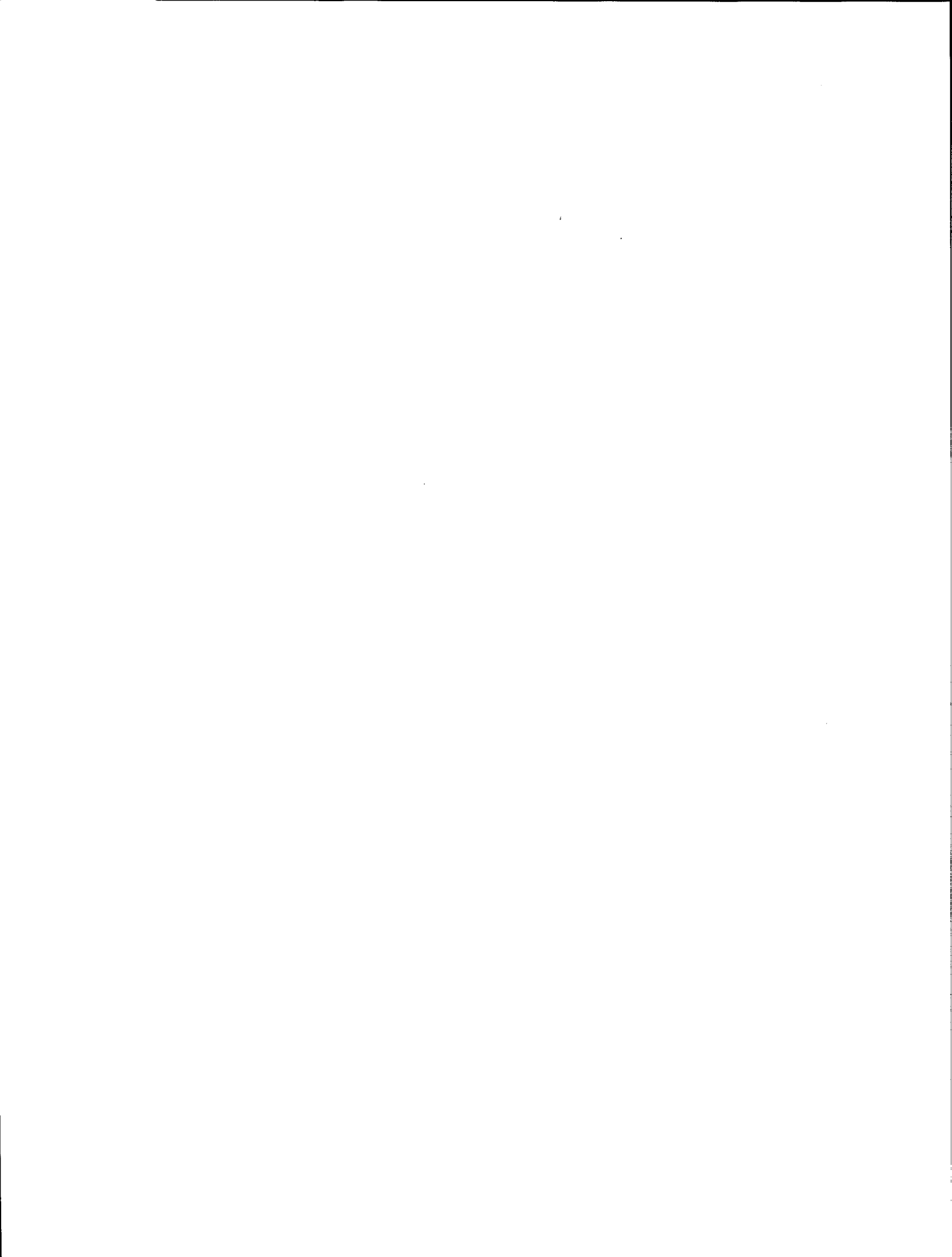
The SPOC software library contains programs to address these model calibration requirements which are reviewed through selected sample runs. References to the appropriate software are given.

RÉSUMÉ

Les modèles empiriques ou phénoménologiques qui représentent le comportement de la plupart des unités de traitement des minerais, demandent d'être calibrés lors de leur développement et lors de mises à jour ultérieures. Les techniques requises pour de telles calibrations vont de la simple régression linéaire à la programmation non-linéaire multivariable. La librairie des programmes du projet SPOC contient les programmes et méthodes nécessaires à la résolution de ces problèmes. Ce chapitre les passe en revue à l'aide d'exemples simples et donne les références appropriées.

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. INTRODUCTION

Mineral processing units are described by phenomenological models, i.e., models in which the equations are based on a theory of the process but contain parameters which must be obtained by experiment on the process itself (1). The computation of these parameters is called *model calibration* and constitutes a crucial step for successful model implementation in a given industrial environment.

One of the advantages of process simulation is that it takes into consideration a range of experimental conditions that can always be extended, provided the models are calibrated against an extended database. It is, therefore, essential that some methods and tools for calibration be available in any process modelling package. Such

methods range from simple linear regressions to complex and computer intensive non-linear optimization algorithms.

This chapter is intended as an introduction to more detailed discussions in the "SPOC Manual" or elsewhere in the literature. The various concepts are introduced in an empirical manner rather than in the rigorous mathematical derivations found in specialized mathematical publications.

Model calibration is also referred to as model parameterization, model parameter estimation, or model tuning.

MODEL CALIBRATION

2. SEARCH FOR BEST ESTIMATES

Most books on statistics discuss the subject of parameter estimation (2,3). A very common example of parameter estimation is the curve fitting of experimental data. Most features of a search for best estimates can be discussed in the simple case of linear regression, i.e., the calibration of the best estimates of the two parameters of the equation of a linear relationship between two variables. The method is presented in Appendix A of Chapter 4 of the "SPOC Manual".

If n different measurements of variables x and y have been collected, the best estimates of the intercept a and the slope b of the regression line representing the linear relationship between the two variables are usually obtained by minimizing the following criterion:

$$\sum_{i=1}^n (y_i - a - bx_i)^2 = \text{minimum} \quad \text{Eq 1}$$

In general, if \hat{y}_i represents the model prediction of variable y_i , the best estimate criterion of a model is expressed as:

$$\sum_{i=1}^n (y_i - \hat{y}_i)^2 = \text{minimum} \quad \text{Eq 2}$$

The parameter estimation problem is therefore also called a least-squares problem (LS). Several other criteria can be used, in particular:

the weighted least-square:
$$\sum \frac{(y_i - \hat{y}_i)^2}{\sigma_i} \quad \text{Eq 3}$$

where σ_i is the standard deviation of measurement i , assumed to be gaussian, unbiased and uncorrelated to others.

The chi-square criterion is also frequently used, especially to check "the goodness of fit" of two statistical distributions (2).

It is expressed by:

$$\sum \frac{(y_i - \hat{y}_i)^2}{\hat{y}_i} = \text{minimum} \quad \text{Eq 4}$$

The solution of a parameter estimation problem can be obtained by two families of methods:

1. the analytical solution
2. the computer simulation solution.

2.1 THE ANALYTICAL SOLUTION

When the mathematical relation between the input and output variables of a model is simple, the least-squares solution can be obtained by direct mathematical derivation from the least-squares criterion.

A simple example of linear regression illustrates this approach. The solution of Equation 1 can be obtained by equating the partial derivatives of the LS criterion to zero:

$$a = \frac{(\sum y_i)(\sum x_i^2) - (\sum x)(\sum x_i y_i)}{n \sum x_i^2 - (\sum x_i)^2} \quad \text{Eq 5}$$

$$b = \frac{n \sum x_i y_i - (\sum x_i)(\sum y_i)}{n \sum x_i^2 - (\sum x_i)^2} \quad \text{Eq 6}$$

The parameter estimation can, therefore, be done by direct computation of parameters a and b from experimental data. (See also Appendix F, Chapter 7.3, "SPOC Manual", for a matrix solution of the least-squares problem.)

As the mathematical form of the relationship between y and x becomes more complex, the analytical derivation of the model parameters also becomes increasingly difficult and finally impossible. As an example, consider the case of a ball-mill model as discussed in Chapter 5.2 of the "SPOC Manual".

It can be represented by a general equation:

$$\mathbf{P} = \mathbf{G}(\mathbf{B}, \mathbf{S}, \text{RTD}) \cdot \mathbf{F} \quad \text{Eq 7}$$

where

- \mathbf{P} = product size distribution
- \mathbf{F} = feed size distribution
- \mathbf{G} = grinding operator, function of \mathbf{B} , \mathbf{S} , RTD
- \mathbf{B} = breakage function
- \mathbf{S} = selection function
- RTD = residence time distribution function

\mathbf{B} and \mathbf{S} are two model parameters that need calibration in order to fit the general model to particular experimental data. The grinding operator, \mathbf{G} , is a product of matrices and a direct derivation of an analytical solution to estimate \mathbf{B} and \mathbf{S} , although feasible, requires fairly complex matrix algebra (4).

Lawson and Hanson (5) present an extensive discussion of least-squares problems, some of which have been applied in the node imbalance minimization algorithm SAMBA, described in Chapters 2 and 2.1 of the "SPOC Manual".

2.2 THE COMPUTER SIMULATION SOLUTION

The estimation of model parameters that minimize Equation 1 can also be done by repeatedly computing the criterion for different values of parameters a and b until a satisfactory couple, a, b is found for which the criterion is minimum.

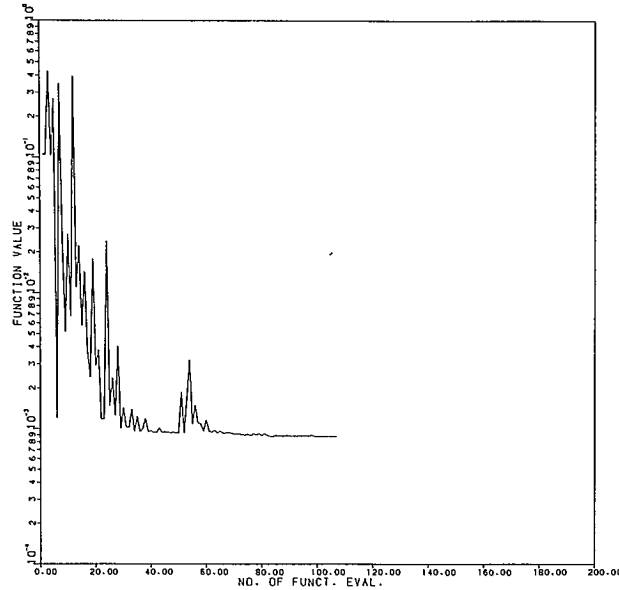
This method is also known as *direct search*. It takes full advantage of the speed of computation in modern computers to find a minimum without explicit derivation of the least-squares function.

Nevertheless, no matter how fast the computer, the large number of possible combinations of values for the unknown parameters requires a search strategy in order to reach the minimum in as few steps as possible.

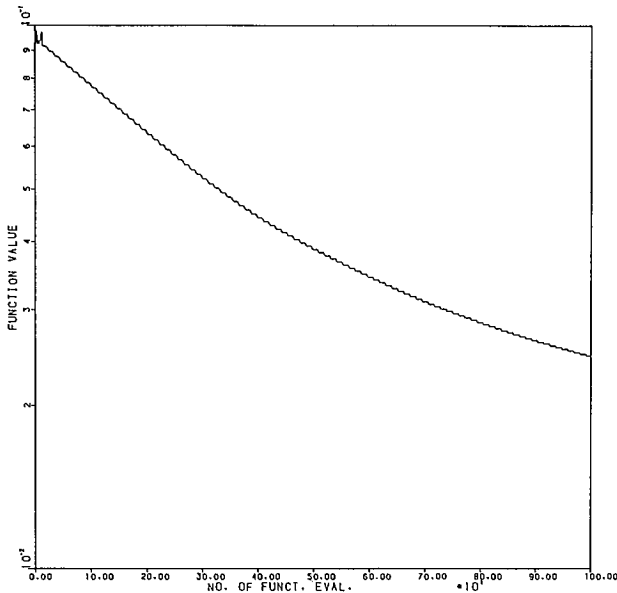
A large number of algorithms have, therefore, been developed, some of which have become well known and widely applied (e.g., SIMPLEX, POWELL, ROSENBROCK). They differ by the strategy they use to vary successively the various search parameters, the magnitude and

direction of each computation step in the parameter space, and the application of a stopping criterion.

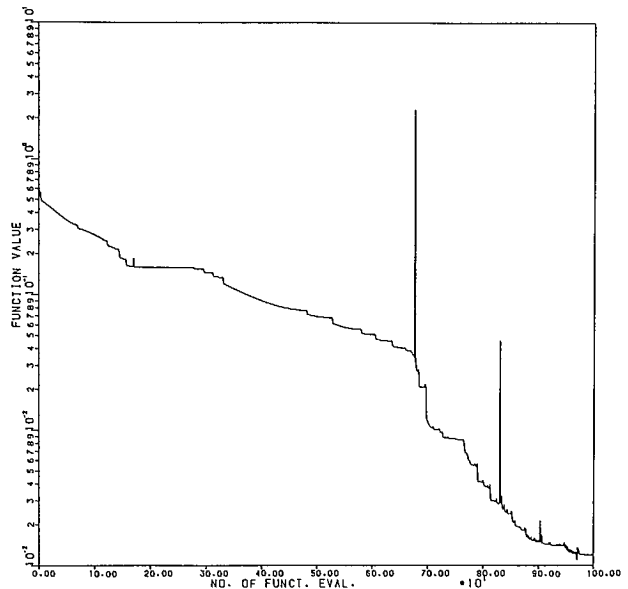
Himmelblau (6) has published a detailed comparison of some of these algorithms that can be very helpful for a user who wants to compare the performance of more recent programs. Source listings for several such algorithms have been available since the early '70s (7) and Figure 1 illustrates how the computation pattern may vary from one algorithm to another.



a) SIMPLEX - RUN63 (BE)



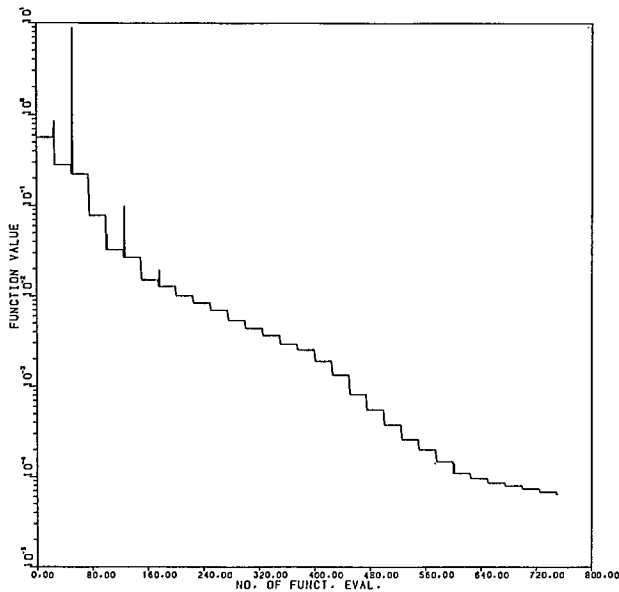
b) ROSENBROCK - RUN113 (BE)



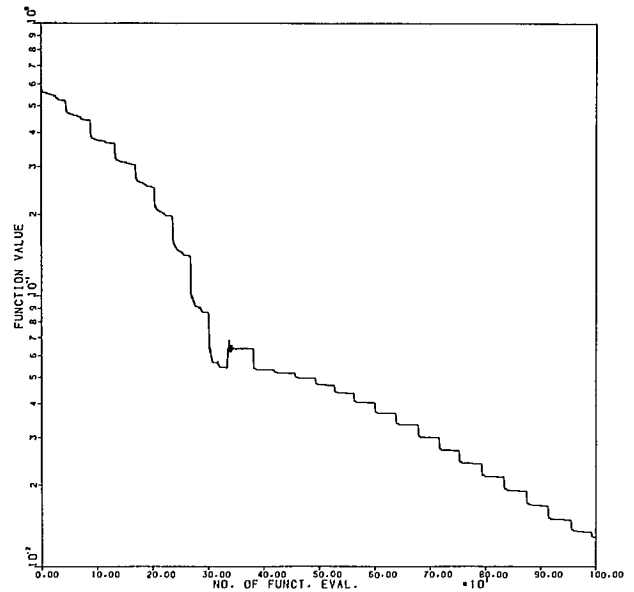
c) POWELL - RUN201 (BE)

Figure 1. Objective function vs iteration number

a) SIMPLEX; b) ROSENBROCK; c) POWELL; d) ZXMIN;
e) HOOKE



d) ZXMIN - RUN203 (BE)



e) HOOKE - RUN204 (BE)

The performance of a given method varies also from one problem to another depending on the shape of the response surface, making it very difficult to rate the programs in general. The source availability, robustness, and documentation are often the main reasons for selecting one program rather than another.

The STAMP program, described in Chapter 7.1 of the "SPOC Manual", features three of the most available and performing algorithms; namely BOTM by Powell (7), a SIMPLEX version modified by F. Kelly (7,8), and ROSEN by Rosenbrock (7).

In general, the user needs to provide a FORTRAN subroutine that calculates the objective function to be minimized, i.e., in most cases the least-squares criterion. This subroutine receives from the supervisory program the modified values of the search parameters and returns the corresponding value of the objective function. This value is compared to the previous ones and one of the search parameters is modified by one step length, according to the particular scheme used in the driver. Some programs use a fixed step length, others vary the step length according to the slope of the objective function in the direction being searched.

The BOTM algorithm uses the conjugate direction method, briefly outlined in Appendix E, Chapter 3.1 of the "SPOC Manual". This algorithm is also used in FINDBS, RTD, and MIXERS programs, described in Chapters 7.2 and 7.3

FINDBS calculates the breakage and selection function parameters of the kinetic ball-mill model, as outlined in Equation 7.

RTD and MIXERS calculate the best-fit residence time distribution and the best-fit tank-in series model that correspond to given tracer measurements and circuit recycling conditions.

Model calibration by the computer simulation solution follows the following general scheme:

1. First estimates of parameters.
2. Computation of LS criterion.
3. Comparison with previous LS criterion and convergence check.
4. If converged, print results and exit.
5. New estimates of parameters.
6. Return to step 2.

When process unit models are being calibrated, the LS criterion is often the sum of squares of differences between calculated and observed product variables. For instance, a ball-mill model calibration may involve numerous pairs of feed-product size distributions corresponding to a wide range of operating conditions. In the FINDBS program, up to five different feeds can be used to calculate batch-grinding parameters and for each feed, up to three product size distributions corresponding to three different grinding times.

3. MODEL CALIBRATION EXAMPLES

Although the model calibration techniques discussed above are illustrated in various other chapters of the "SPOC Manual", especially Chapters 4, 4.1, 7.1, 7.2, and 7.3, a series of other examples is presented below.

3.1 CALIBRATION OF AN ON-LINE X-RAY FLUORESCENCE ANALYZER

Quantitative x-ray fluorescence analysis involves reading x-ray intensities emitted by some elements in the ore matrix and converting them into concentrations.

The effect of instrumentation on the intensities is usually cancelled out by measuring intensity ratios between the actual sample and pure element standard. The inter-element effect, also called matrix effect, is more complex although it can be expressed as a function of fundamental atomic parameters (9). In practice, if similar samples of known composition are available, the matrix effect correction can be considerably simplified or altogether made unnecessary.

In on-stream analysis, matrix effect is much reduced by the fact that the analysis is carried out in the slurry and

the content of solids is usually in the range of 10 to 30% (10). It is possible to express the concentration of an element i as a function of its intensity ratioed to the backscatter solid content of the slurry and intensity ratios from other elements that have interelement effect as follows:

$$C_i = a \left(\frac{R_i + \sum R_j + b}{\% \text{ solids}} \right) + c \quad \text{Eq 8}$$

where a , b and c are the parameters; R_i and R_j are the ratios of the intensity to the backscatter peak of a monochromatic beam if a radioisotope source or an x-ray tube with secondary target is used. The % solids can be related to the backscatter peak as follows:

$$\% \text{ solids} = a' + \frac{b'}{S_c} + \frac{c'}{S_c^2} \quad \text{Eq 9}$$

The sample run shows how the STAMP program can be used to calculate the parameters of the above equations that best fit a set of experimental data.

3.1.1 Sample run

STAMP EXECUTION STARTS NOW

WELCOME TO THE STAMP PACKAGE

HERE IS A LIST OF MODULES AND THEIR OPTIONS

MODULES	OPTIONS	SUB-OPTIONS
EDIT	MODIFY A VARIABLE	ADD AN OBSERVATION DELETE AN OBSERVATION REENTER COMPLETE OBSERVATIONS REENTER WITH FUNCTION MODIFY AN OBSERVATION DIRECT ENTRY FUNCTION ENTRY
	CREATE A VARIABLE	
	DELETE A VARIABLE	
	EXAMINE VARIABLES	INDEX OF VARIABLES VALUES OF VARIABLES
.....		
PLOTS	X(I) VS I Y(I) VS X(I) EXAMINE VARIABLES	
.....		
C TO CONTINUE : C		
.....		
STATS		
.....		
CORRELATION		
.....		
REGRESSIONS	MULTIPLE LINEAR REGRESSION SIMPLE LINEAR REGRESSION	X ON Y Y ON X WEIGHTED X AND Y ORTHOGONAL
	STEPWISE REGRESSION POLYNOMIAL REGRESSION EXAMINE VARIABLES	
.....		
NON LINEAR OPTIMIZATION	EDITING FUNCTION POWELL METHOD SIMPLEX METHOD ROSENBROCK METHOD	

TO CONSULT A MENU, ENTER 99
AND TO EXIT OF A MODULE, ENTER 0.

C TO CONTINUE : C
PRINCIPAL MODULES

1 = EDIT
2 = PLOTS
3 = STATS
4 = CORRELATION
5 = REGRESSIONS
6 = NON LINEAR OPTIMIZATION
99 = HELP
0 = STOP

STAMP (HELP=99) : 5
 REGRESSIONS (HELP=99) : 99
 REGRESSIONS

- 1 = MULTIPLE LINEAR REGRESSION
 2 = SIMPLE WEIGHTED REGRESSION
 3 = STEPWISE REGRESSION
 4 = POLYNOMIAL REGRESSION
 5 = EXAMINE VARIABLES
 99 = HELP
 0 = EXIT

REGRESSIONS (HELP=99) : 4
 INSTRUCTION Y/N?Y

ENTERING DATA IDENTIFY THE DEPENDANT VARIABLE
 IDENTIFY THE INDEPENDANT VARIABLE
 IDENTIFY THE DEGREE OF POLINOMIAL

RESULTS 1 SCREEN : STATISTICS ON PARAMETERS
 2 SCREEN : ANOVA TABLE

ENTER NAME (DEP) : SOL
 ENTER NAME (IND) : SCAT
 ENTER DEGREE OF POLYNOMIAL : 2
 POLYNOMIAL REGRESSION OF DEGREE 1
 INTERCEPT -.2081309E+02
 REGRESSION COEFFICIENTS
 .1344505E+03

ANALYSIS OF VARIANCE FOR 1 DEGREE POLYNOMIAL

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	IMPROVEMENT IN TERMS OF SUM OF SQUARES
DUE TO REGRESSION	1	865.72078	865.72078	932.96766	865.72078
DEVIATION ABOUT REGRESSION	10	9.27922	.92792		
TOTAL	11	875.00000			

POLYNOMIAL REGRESSION OF DEGREE 2
 INTERCEPT -.2206617E+01
 REGRESSION COEFFICIENTS
 .1174169E+02 .1941530E+03

ANALYSIS OF VARIANCE FOR 2 DEGREE POLYNOMIAL

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F VALUE	IMPROVEMENT IN TERMS OF SUM OF SQUARES
DUE TO REGRESSION	2	870.48533	435.24267	867.65702	4.76455
DEVIATION ABOUT REGRESSION	9	4.51467	.50163		
TOTAL	11	875.00000			

POLYNOMIAL REGRESSION OF DEGREE 2

TABLE OF RESIDUALS

OBSERVATION NO.	X VALUE	Y VALUE	Y ESTIMATE	RESIDUAL
1	.22252	10.00000	10.01955	-.01955
2	.30741	20.00000	19.75034	.24966
3	.37908	30.00000	30.14375	-.14375
4	.22789	10.00000	10.55274	-.55274
5	.31696	20.00000	21.01997	-1.01997
6	.38625	30.00000	31.29404	-1.29404
7	.26434	15.00000	14.46380	.53620
8	.34352	25.00000	24.73877	.26123
9	.40667	35.00000	34.67740	.32260
10	.26427	15.00000	14.45581	.54419
11	.34235	25.00000	24.56836	.43164
12	.40453	35.00000	34.31546	.68454

REGRESSIONS (HELP=99) : 1
INSTRUCTION Y/N?Y

ENTERING DATA IDENTIFY THE DEPENDANT VARIABLE
IDENTIFY THE INDEPENDANT VARIABLES
ENTER STOP TO FINISH

RESULTS 1 SCREEN : STATISTICS ON PARAMETERS
2 SCREEN : ANOVA TABLE
3 SCREEN : INTERVALS ESTIMATED Y AND PARAMETERS

ENTER "STOP" FOR FINISH
ENTER NAME (DEP) : CU%
ENTER NAME (IND) : CU-S
ENTER NAME (IND) : ZN-S
ENTER NAME (IND) : I-S
ENTER NAME (IND) : STOP

***** INTMLR *****

CURVE FITTING FOR MULTI-VARIABLE LINEAR REGRESSION
 $Y = B_0 + B_1(X_1 - \bar{X}_1) + B_2(X_2 - \bar{X}_2) + \dots$
WHERE \bar{X}_1 , \bar{X}_2 ARE THE (WEIGHTED) MEAN VALUES
OF X_1 , X_2 RESPECTIVELY

ANY REPEAT Y FOR SAME X VALUES ?
N

DID YOU PREPARE THE ERROR VARIANCE OF Y ?
N

VARIABLE NO.	WEIGHTED MEAN	STANDARD DEVIATION	CORRELATION X VS Y	REGRESSION COEFFICIENT	COMPUTED T VALUE
2	.00219	.00120	.03071	491.64198	2.99231
3	.00864	.00274	.04479	146.45414	1.81206
4	.05294	.02485	.07673	-13.27811	3.46193
DEP.	4.43000	.84676			

T (8), 95 %: 2.31 (TWO TAILS)

INTERCEPT 4.43000
 INTERCEPT B0-B1*X1BAR-B2*X2BAR-... 2.79143
 MULTI-CORRELATION COEFFICIENT .97340
 STD. ERROR OF ESTIMATE .22748

COVARIANCE MATRIX OF REGRESSION COEFFICIENTS :

.4312E-02	0.	0.	0.
0.	.2700E+05	-.1212E+05	.1975E+03
0.	-.1212E+05	.6532E+04	-.1672E+03
0.	.1975E+03	-.1672E+03	.1471E+02

 DO YOU WANT THE TABLE OF RESIDUALS ?Y

 TABLE OF RESIDUALS

CASE NO.	Y VALUE	Y ESTIMATE	RESIDUAL
1	5.22000	5.42330	-.20330
2	5.22000	5.41521	-.19521
3	5.22000	5.38630	-.16630
4	5.25000	5.00928	.24072
5	5.25000	5.05496	.19504
6	5.25000	4.85049	.39951
7	3.49000	3.37521	.11479
8	3.49000	3.53403	-.04403
9	3.49000	3.53874	-.04874
10	3.76000	3.85118	-.09118
11	3.76000	3.91179	-.15179
12	3.76000	3.80952	-.04952

DO YOU WISH TO SAVE Y-ESTIMATES AND RESIDUALS?N

 DO YOU WANT THE ANALYSIS OF VARIANCE FOR THE MODEL ?Y

 ANALYSIS OF VARIANCE TABLE

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F-RATIO
REG	7.4730	3	2.4910	48.1371
RES	.4140	8	.0517	
TTL	7.8870	11	.7170	
R**2 (REG/TTL)=			.94751	

DO YOU WANT THE 95% CONFIDENCE INTERVALS FOR Y ESTIMATE AND THE PARAMETERS ?Y

95% CONFIDENCE INTERVALS FOR Y AND Y*
 $Y = B_0 + B_1*(X_1 - X_{1BAR}) + B_2*(X_2 - X_{2BAR}) + \dots$
 $Y^* = B_0 + B_1*(X_1 - X_{1BAR}) + B_2*(X_2 - X_{2BAR}) + \dots + E$
 (E IS THE ERROR ON Y)

Y ESTIMATE	Y LOWER LIMIT	Y UPPER LIMIT	Y* LOWER LIMIT	Y* UPPER LIMIT
5.42330	5.06434	5.78226	4.78761	6.05899
5.41521	5.12463	5.70579	4.81547	6.01494
5.38630	4.98055	5.79205	4.72306	6.04953
5.00928	4.69565	5.32291	4.39804	5.62052
5.05496	4.81084	5.29909	4.47631	5.63362
4.85049	4.60876	5.09222	4.27284	5.42814
3.37521	3.03241	3.71801	2.74850	4.00191
3.53403	3.27727	3.79080	2.94993	4.11814
3.53874	3.25462	3.82286	2.94210	4.13537
3.85118	3.52168	4.18067	3.23165	4.47070
3.91179	3.62749	4.19608	3.31507	4.50851
3.80952	3.57903	4.04001	3.23648	4.38256

95% CONFIDENCE INTERVALS FOR PARAMETERS

	LOWER LIMIT	UPPER LIMIT
B 0	4.27855	4.58145
B 1	112.71340	870.57057
B 2	-39.94526	332.85353
B 3	-22.12382	-4.43240

REGRESSIONS (HELP=99) : 0
 STAMP (HELP=99) : 0

3.2 CALIBRATION OF A BALL-MILL MODEL FROM A BATCH-GRINDING EXPERIMENT

In a batch-grinding experiment, the model parameters of Equation 7 are the breakage and selection functions, since the residence time in the mill is exactly known for all particles. A typical application of model calibration is therefore to compute the breakage and selection functions that best describe the behaviour of a given ore in a given mill, so that the outcome of proposed experiments in the same mill with the same ore can be simulated. If the range of calibration of the model

includes grinding times of up to t minutes, the model parameters can safely be applied to shorter grinding times. The solution to this problem is readily obtained by using the FINDBS program documented in Chapter 7.2, the "SPOC Manual".

The sample run that follows is also presented in Chapter 7.2 of the "SPOC Manual".

3.2.1 Sample run

DISTRIBUTION AND RATE FUNCTION DETERMINATION

BATCH GRINDING DATA TEST

```

OPTIONS: IBOPT, IBFIX, ISOPT, ISFIX, MIXERS : 4 0 4 0 0
ESTIMATE OF B CONSTANT 1: .5
ESTIMATE OF B CONSTANT 2: 1.
ESTIMATE OF B CONSTANT 3: 20.
ESTIMATE OF B CONSTANT 4: .2
ESTIMATE OF S CONSTANT 1: .5
ESTIMATE OF S CONSTANT 2: .2
ESTIMATE OF S CONSTANT 3: .1
ESTIMATE OF S CONSTANT 4: .1
CRITERION TYPE : 3
SEARCH OPTION : 3
  
```

```

ITERATION 10          236 FUNCTION VALUES          F = .57410502E+01
FINAL CONSTANTS (TOP SIZE = 2.022) S.D.RESIDS. = .320          D.F. = 56
  
```

```

B1 = .3980
B2 = .9202
B3 = 20.00
B4 = .1367
S1 = .2605
S2 = .3178
S3 = .2075E-02
S4 = .9039E-01
  
```

SIZE	FEED	PRODUCT - OBSERVED/PREDICTED	
		2.00	4.00
8/10M	62.98	30.50 / 32.11	15.38 / 16.38
10/14M	36.72	40.39 / 37.07	34.32 / 29.11
14/20M	.16	11.58 / 14.40	15.87 / 20.30
20/28M	0.00	6.00 / 5.15	10.39 / 10.44
28/35M	0.00	3.03 / 2.93	5.78 / 6.07
35/48M	0.00	2.24 / 2.12	4.43 / 4.33
48/65M	0.00	1.46 / 1.59	3.08 / 3.32
65/100M	0.00	1.09 / 1.19	2.28 / 2.56
100/150M	0.00	.85 / .89	1.85 / 1.95
150/200M	0.00	.73 / .65	1.66 / 1.46
200/270M	0.00	.55 / .48	1.17 / 1.07
PAN	.18	1.58 / 1.43	3.81 / 3.02

SIZE	FEED	PRODUCT - OBSERVED/PREDICTED	
		2.00	4.00
8/10M	0.00	0.00 / 0.00	0.00 / 0.00
10/14M	0.00	0.00 / 0.00	0.00 / 0.00
14/20M	59.26	33.45 / 35.13	19.38 / 20.82
20/28M	25.30	30.89 / 29.29	27.29 / 26.32
28/35M	7.80	14.33 / 14.29	17.47 / 17.90
35/48M	4.26	8.70 / 7.81	11.98 / 11.04
48/65M	1.97	5.12 / 4.65	7.57 / 7.19
65/100M	.55	2.39 / 2.61	4.41 / 4.67
100/150M	.24	1.54 / 1.69	3.00 / 3.24
150/200M	.24	1.02 / 1.29	2.50 / 2.44
200/270M	.16	.68 / .94	1.66 / 1.79
PAN	.24	1.88 / 2.31	4.74 / 4.60

3.3 CALIBRATION OF A HYDROCYCLONE MODEL

Hydrocyclone performance can be described by plotting the fraction of feed material that reports to the underflow as a function of the particle size. A detailed model of the hydrocyclone by Plitt is discussed in Chapter 5.2 of the "SPOC Manual". The model is represented by a general equation of the reduced efficiency curve:

$$cc = 1 - e^{-0.693 (d/d50c)^m} \quad \text{Eq 10}$$

where cc is the corrected efficiency
 d is the particle size
 $d50c$ is the corrected diameter of equipartition.

If m and $d50c$, the two model parameters of Equation 10 are calculated, the corrected efficiency curve cc is defined for all the d values and the actual efficiency, $c = f(d)$, can be calculated from:

$$cc = \frac{c - R_f}{1 - R_f} \quad \text{Eq 11}$$

where R_f is called the water-split coefficient, or fraction of feed water reporting to the underflow.

R_f , m and $d50c$ are therefore the three parameters that need to be calibrated to fully define the hydrocyclone behaviour according to the Plitt model.

3.3.1 HCAL Program

HCAL is a program for the calibration of hydrocyclone efficiency curves. The program uses the size distributions of the feed and overflow streams and the corresponding solids flow rates to compute the values of the model parameters that best fit the experimental data. The experimental data must be coherent on a mass balance point of view. HCAL uses a computer simulation approach to find the solution.

3.3.1.1. Program capabilities

HCAL contains several options for the user to select during the execution. Two model types, four criteria types and two direct search methods are proposed. A straightforward simulation capability is also available. Finally, data can be entered in a batch mode or interactively.

The two models proposed to represent the efficiency curves are the Plitt model defined in Section 3.3 and the Lynch model (11) represented by the following equation:

$$cc = \frac{e^{md/d50c} - 1}{e^{md/d50c} + e^{m - 2}} \quad \text{Eq 12}$$

where cc , d and $d50c$ have the same meaning as in Equation 10. The actual efficiency curve c is calculated from Equation 11 and Equation 12 as for the Plitt model.

Both models, therefore, require the knowledge of three parameters to define the actual efficiency curve c .

HCAL uses the simulation method to calculate the values of the three parameters. The criterion to be minimized may be one of the four following as selected by the user:

- a least-squares criterion on observed and computed underflow mass fractions;
- a least-squares criterion on experimental and computed efficiency values;
- a chi-square criterion on observed and computed mass fractions;
- a chi-square criterion on experimental and computed efficiency values.

Although other criteria types could be used, the four proposed in HCAL should be sufficient in many cases.

For the user's comfort, two direct search methods are proposed: the BOTM algorithm and the SIMPLEX algorithm. During the execution, if the user does not select any of them, a straightforward simulation takes place by using the estimated values of the three parameters entered in a typical run.

When a run is successfully completed, the user is presented with a command menu. The user is given a chance to change the model type, the criterion type, the direct search algorithm or the estimated values of the three parameters before restarting the program for a new run. The purpose of this is to compare different models obtained from identical data but under different search conditions.

3.3.1.2 Data entry

HCAL is an interactive program, therefore data required to run HCAL are entered interactively, although most of the data could also be entered in a batch mode. Interactive entries are read from the logical unit 1 while batch entries are read from the logical unit 2. All entries are in a free-format. The mode of data entry is selected by the user via the command menu (see Options 1 and 2 in Section 3.3.2).

Interactive or batch entries

- A run identification up to 60 characters.
- The number of size intervals and feed size distributions: up to 20 size intervals (pan included) and 10 different feed size distributions are allowed.
- The sieve apertures (microns): the first value entered must be the aperture of the smallest sieve that all particles pass through. The last value entered here is therefore the aperture of the smallest sieve used for the sieve analysis. These values are very important at calculation time since they are used to compute the d values of Equations 10 or 12. d is the arithmetic average of the apertures of two successive sieves.
- For each data set, the user has to enter: the feed size distribution (in wt % retained); the overflow size distribution (in wt % retained); and the feed and overflow solids flow rates.
- The efficiency curve model type: 1 stands for the Lynch model, 2 stands for the Plitt model.
- The estimated values of the three model parameters; d_{50c} , m and R_f . d_{50c} must be in microns and R_f in per cent.
- The direct search algorithm: 1 stands for BOTM, 2 stands for SIMPLEX. If 0 is entered in place, a straight-forward simulation will occur at execution time, i.e., the estimated values of the three model parameters will be taken as *true* values by HCAL and will not be modified.
- The criterion type: 1 to 4 can be entered as explained in the program capabilities section.

Interactive-only entries

- The answer to the command menu: see Section 3.3.2.
- The parameter values that control the direct search algorithm: default values are proposed by the program. The user is referred to the STAMP program (Chapter 7.1, "SPOC Manual") for more details about these controls.
- All the modifications to the user selectable options after a successful run.

3.3.1.3 Program output

HCAL produces two reports. The first one is displayed on the user's screen and besides the three parameter values gives mainly a table which contains the feed size distribution, the underflow size distribution (observed and computed), the overflow size distribution (observed and computed), the efficiency values (observed and computed), and the various solids flow rates (observed and computed).

The second report is not displayed. It is written onto logical unit 3 and contains the data and options used during the last successful run of the program. That file is suitable for an ulterior run of HCAL using the batch data entry mode.

3.3.1.4 Error messages

During data entry, several checks are performed to test for data validity. Nevertheless, problems may occur at execution time. In that event, both direct search algorithms display their own error messages (see Chapter 7.1).

3.3.2 Program usage

When program HCAL is activated the user is presented with a menu of 3 options:

- 0 = STOP EXECUTION
- 1 = INTERACTIVE DATA ENTRY MODE
- 2 = BATCH DATA ENTRY MODE

Then according to the direct search algorithm chosen, the default controls are displayed and the user has the possibility to enter other values.

At the end of the execution a new menu of 7 options is presented:

- 0 = STOP EXECUTION
- 1 = RESTART FROM SCRATCH
- 2 = RESTART WITH PRESENT DATA
- 3 = CHANGE EFFICIENCY MODEL TYPE
- 4 = CHANGE OPTIMIZATION ALGORITHM
- 5 = CHANGE CRITERION TYPE
- 6 = CHANGE D_{50C} , M , $R_f(\%)$ ESTIMATES

3.3.3 HCAL sample run

The following sample run is based on industrial data. Three composite samples were taken around a pack of hydrocyclones. They were analyzed in a standard sieve column and a Microtrac. Solids flow rates were also measured. Then data were processed by the BILMAT package (see Chapter 3.1) to make the data consistent on a mass balance point of view.

The sample run shows the usage of HCAL in the batch data entry mode. A least-squares on the underflow mass fractions is first used to find the three parameter values of a Plitt model. Then the program is restarted on the basis of an X^2 criterion. The results show acceptable fitting.

```
CALIBRATION OF HYDROCYCLONE EFFICIENCY CURVES
      C = CC + RF * (1 - CC)

MENU :

      0 = STOP EXECUTION
      1 = INTERACTIVE DATA ENTRY MODE
      2 = BATCH DATA ENTRY MODE

COMMAND : 2

ENTER RUN IDENTIFICATION :

HYDROCYCLONE MODEL: CALIBRATION OF THE EFFICIENCY CURVE

ENTER NUMBER OF SIZE INTERVALS (PAN INCLUDED)
AND NUMBER OF FEED SIZE DISTRIBUTIONS :
16 3

ENTER PASSING SIEVE APERTURES (MICRONS) :

4000. 2828. 2000. 1414. 1000. 707. 500. 353.5 250. 176.8 125.
88.4 62.5 44.2 31.25 22.1

SIZE DISTRIBUTIONS (WEIGHT %)

FOR FEED # 1 :

.18 .38 1.28 3.93 6.01 6.98 8.99 10.99 11.61 10.44 6.61 5.03
4.59 6.32 2.85 13.8

FOR OVERFLOW # 1 :

0. 0. .02 .31 .55 .67 1.01 2.57 6.2 11.43 10.73 9.5 9.26 12.57
5.92 29.26

FOR SET # 1, ENTER FEED AND OVERFLOW SOLID FLOWRATES :

351. 89.49

FOR FEED # 2 :

.02 .57 1.29 2.68 4.38 5.16 7.09 9.64 11.96 12.27 7.46 5.98
5.53 7.13 2.88 15.96

FOR OVERFLOW # 2 :

0. 0. .01 .18 .34 .42 .67 1.35 3.73 10.21 11.1 10.57 10.54 13.32
5.24 32.32

FOR SET # 2, ENTER FEED AND OVERFLOW SOLID FLOWRATES :

241.06 80.4
```

FOR FEED # 3 :
.02 .23 .76 2.36 3.92 4.67 5.87 8.85 11.25 13.24 8.06 6.33 5.79
7.6 3.01 18.05

FOR OVERFLOW # 3 :
0. 0. 0. .01 .07 .1 .21 1.05 2.12 7.56 9.78 9.8 10.33 14.85
6.21 37.91

FOR SET # 3, ENTER FEED AND OVERFLOW SOLID FLOWRATES :
202.29 69.9

POSSIBLE MODEL TYPES :
1 = LYNCH
2 = PLITT
YOUR CHOICE (1 OR 2) :
2

ENTER FOR PLITT MODEL, THE VALUES OF
D50C(MICRONS), M AND RF(%) :
156. 2. 37.

POSSIBLE OPTIMIZATION ALGORITHMS :
1 = POWELL
2 = SIMPLEX
0 = NONE OF THEM
YOUR CHOICE (1, 2 OR 0) :
1

POSSIBLE CRITERION TYPES :
1 = LEAST SQUARES ON UNDERFLOW MASS FRACTIONS
2 = LEAST SQUARES ON EFFICIENCY VALUES
3 = CHI SQUARE ON UNDERFLOW MASS FRACTIONS
4 = CHI SQUARE ON EFFICIENCY VALUES
YOUR CHOICE (1 TO 4) :
1

POWELL ALGORITHM
MAXIMUM NUMBER OF ITERATIONS = 40
PRINTING OPTION = 2
ESCALE FACTOR = 1.
TOLERANCES ARE : 7.80000000 .10000000 .01850000

DO YOU ACCEPT THESE DEFAULT VALUES (Y/N)Y

POWELL-BOTM OPTIMIZATION ROUTINE

PARAMETERS

N = 3 MAXIT = 40 ESCALE = 1.00
INITIAL GUESSES (Z) ACCURACY REQUIRED FOR VARIABLES (E)
1.56000000E+02 7.80000000E+00
2.00000000E+00 1.00000000E-01
3.70000000E-01 1.85000000E-02

ITERATION 1 13 FUNCTION VALUES F = .57332332E+02
.13668911E+03 .19435596E+01 .37000000E+00

ITERATION 2 20 FUNCTION VALUES F = .57327789E+02
.13626538E+03 .19413858E+01 .36998221E+00

END OF MINIMIZATION PROCESS

OPTIMUM VALUE OF F = .57327789E+02
VALUES OF THE VARIABLES

Z(1) = .13626538E+03

Z(2) = .19413858E+01

Z(3) = .36998221E+00

HYDROCYCLONE MODEL: CALIBRATION OF THE EFFICIENCY CURVE

PLITT MODEL PARAMETERS :
D50C = 136.265 M = 1.941 RF = 37.00

FOR SIZE DISTRIBUTION # 1

SIZE	FEED	UF OBS	UF CALC	OF OBS	OF CALC	C OBS	C CALC
4000.	.18	.24	.24	0.00	.00	1.000	1.000
2828.	.38	.51	.52	0.00	.00	1.000	1.000
2000.	1.28	1.71	1.74	.02	.00	.996	1.000
1414.	3.93	5.17	5.35	.31	.00	.980	1.000
1000.	6.01	7.88	8.18	.55	.00	.977	1.000
707.	6.98	9.14	9.50	.67	.00	.976	1.000
500.	8.99	11.72	12.22	1.01	.04	.971	.999
354.	10.99	13.87	14.59	2.57	1.02	.940	.975
250.	11.61	13.46	13.90	6.20	5.27	.864	.880
177.	10.44	10.10	10.33	11.43	10.74	.721	.727
125.	6.61	5.20	5.32	10.73	10.20	.586	.591
88.	5.03	3.50	3.38	9.50	9.59	.518	.494
63.	4.59	2.99	2.73	9.26	9.75	.486	.437
44.	6.32	4.18	3.48	12.57	14.18	.493	.405
31.	2.85	1.80	1.51	5.92	6.58	.470	.388
22.	13.80	8.51	7.01	29.26	32.61	.459	.373
SFR	351.000	261.510	257.911	89.490	93.089		

FOR SIZE DISTRIBUTION # 2

SIZE	FEED	UF OBS	UF CALC	OF OBS	OF CALC	C OBS	C CALC
4000.	.02	.03	.03	0.00	.00	1.000	1.000
2828.	.57	.86	.82	0.00	.00	1.000	1.000
2000.	1.29	1.93	1.85	.01	.00	.997	1.000
1414.	2.68	3.93	3.84	.18	.00	.978	1.000
1000.	4.38	6.40	6.28	.34	.00	.974	1.000
707.	5.16	7.53	7.40	.42	.00	.973	1.000
500.	7.09	10.30	10.15	.67	.03	.968	.999
354.	9.64	13.79	13.48	1.35	.78	.953	.975
250.	11.96	16.08	15.08	3.73	4.76	.896	.880
177.	12.27	13.30	12.79	10.21	11.08	.722	.727
125.	7.46	5.64	6.32	11.10	10.10	.504	.591
88.	5.98	3.68	4.24	10.57	10.00	.410	.494
63.	5.53	3.02	3.46	10.54	10.30	.364	.437
44.	7.13	4.03	4.14	13.32	14.03	.377	.405
31.	2.88	1.70	1.60	5.24	5.83	.393	.388
22.	15.96	7.77	8.54	32.32	33.09	.325	.373
SFR	241.060	160.660	168.190	80.400	72.870		

FOR SIZE DISTRIBUTION # 3

SIZE	FEED	UF OBS	UF CALC	OF OBS	OF CALC	C OBS	C CALC
4000.	.02	.03	.03	0.00	.00	1.000	1.000
2828.	.23	.35	.34	0.00	.00	1.000	1.000
2000.	.76	1.16	1.13	0.00	.00	1.000	1.000
1414.	2.36	3.60	3.50	.01	.00	.999	1.000
1000.	3.92	5.95	5.82	.07	.00	.994	1.000
707.	4.67	7.08	6.93	.10	.00	.993	1.000
500.	5.87	8.86	8.70	.21	.02	.988	.999
354.	8.85	12.97	12.81	1.05	.67	.959	.975
250.	11.25	16.07	14.69	2.12	4.15	.935	.880
177.	13.24	16.24	14.29	7.56	11.08	.803	.727
125.	8.06	7.15	7.07	9.78	10.11	.581	.591
88.	6.33	4.50	4.64	9.80	9.81	.465	.494
63.	5.79	3.39	3.75	10.33	10.00	.384	.437
44.	7.60	3.77	4.57	14.85	13.86	.325	.405
31.	3.01	1.32	1.73	6.21	5.65	.287	.388
22.	18.05	7.56	10.00	37.91	34.68	.274	.373
SFR	202.290	132.390	136.313	69.900	65.977		

MENU :

- 0 = STOP EXECUTION
- 1 = RESTART FROM SCRATCH
- 2 = RESTART WITH PRESENT DATA
- 3 = CHANGE EFFICIENCY MODEL TYPE
- 4 = CHANGE OPTIMIZATION ALGORITHM
- 5 = CHANGE CRITERION TYPE
- 6 = CHANGE D50C,M,RF% ESTIMATES

COMMAND : 2

ENTER RUN IDENTIFICATION :
 EFFICIENCY-- SAME DATA, CHI SQUARE CRITERION

POWELL ALGORITHM

MAXIMUM NUMBER OF ITERATIONS = 40
 PRINTING OPTION = 2
 ESCALE FACTOR = 1.
 TOLERANCES ARE : 6.81326882 .09706929 .01849911

DO YOU ACCEPT THESE DEFAULT VALUES (Y/N)Y

POWELL-BOTM OPTIMIZATION ROUTINE

PARAMETERS

N = 3 MAXIT = 40 ESCALE = 1.00
INITIAL GUESSES (Z) ACCURACY REQUIRED FOR VARIABLES (E)
1.36265376E+02 6.81326882E+00
1.94138577E+00 9.70692884E-02
3.69982212E-01 1.84991106E-02

ITERATION 1 10 FUNCTION VALUES F = .57323739E+02
.13626538E+03 .19307430E+01 .36998221E+00

ITERATION 2 18 FUNCTION VALUES F = .57320208E+02
.13626538E+03 .19307430E+01 .36932719E+00

END OF MINIMIZATION PROCESS

OPTIMUM VALUE OF F = .57320208E+02
VALUES OF THE VARIABLES

Z(1) = .13626538E+03

Z(2) = .19307430E+01

Z(3) = .36932719E+00

EFFICIENCY-- SAME DATA, CHI SQUARE CRITERION

PLITT MODEL PARAMETERS :

D50C = 136.265 M = 1.931 RF = 36.93

FOR SIZE DISTRIBUTION # 1

SIZE	FEED	UF OBS	UF CALC	OF OBS	OF CALC	C OBS	C CALC
4000.	.18	.24	.25	0.00	.00	1.000	1.000
2828.	.38	.51	.52	0.00	.00	1.000	1.000
2000.	1.28	1.71	1.74	.02	.00	.996	1.000
1414.	3.93	5.17	5.35	.31	.00	.980	1.000
1000.	6.01	7.88	8.18	.55	.00	.977	1.000
707.	6.98	9.14	9.50	.67	.00	.976	1.000
500.	8.99	11.72	12.23	1.01	.04	.971	.999
354.	10.99	13.87	14.59	2.57	1.05	.940	.975
250.	11.61	13.46	13.89	6.20	5.31	.864	.879
177.	10.44	10.10	10.33	11.43	10.75	.721	.727
125.	6.61	5.20	5.32	10.73	10.18	.586	.591
88.	5.03	3.50	3.39	9.50	9.57	.518	.495
63.	4.59	2.99	2.73	9.26	9.73	.486	.437
44.	6.32	4.18	3.48	12.57	14.16	.493	.405
31.	2.85	1.80	1.50	5.92	6.57	.470	.388
22.	13.80	8.51	7.00	29.26	32.60	.459	.373
SFR	351.000	261.510	257.788	89.490	93.212		

FOR SIZE DISTRIBUTION # 2

SIZE	FEED	UF OBS	UF CALC	OF OBS	OF CALC	C OBS	C CALC
4000.	.02	.03	.03	0.00	.00	1.000	1.000
2828.	.57	.86	.82	0.00	.00	1.000	1.000
2000.	1.29	1.93	1.85	.01	.00	.997	1.000
1414.	2.68	3.93	3.84	.18	.00	.978	1.000
1000.	4.38	6.40	6.28	.34	.00	.974	1.000
707.	5.16	7.53	7.40	.42	.00	.973	1.000
500.	7.09	10.30	10.16	.67	.03	.968	.999
354.	9.64	13.79	13.47	1.35	.81	.953	.975
250.	11.96	16.08	15.07	3.73	4.80	.896	.879
177.	12.27	13.30	12.78	10.21	11.09	.722	.727
125.	7.46	5.64	6.32	11.10	10.08	.504	.591
88.	5.98	3.68	4.24	10.57	9.99	.410	.495
63.	5.53	3.02	3.46	10.54	10.29	.364	.437
44.	7.13	4.03	4.14	13.32	14.02	.377	.405
31.	2.88	1.70	1.60	5.24	5.83	.393	.388
22.	15.96	7.77	8.53	32.32	33.08	.325	.373
SFR	241.060	160.660	168.103	80.400	72.957		

FOR SIZE DISTRIBUTION # 3

SIZE	FEED	UF OBS	UF CALC	OF OBS	OF CALC	C OBS	C CALC
4000.	.02	.03	.03	0.00	.00	1.000	1.000
2828.	.23	.35	.34	0.00	.00	1.000	1.000
2000.	.76	1.16	1.13	0.00	.00	1.000	1.000
1414.	2.36	3.60	3.50	.01	.00	.999	1.000
1000.	3.92	5.95	5.82	.07	.00	.994	1.000
707.	4.67	7.08	6.93	.10	.00	.993	1.000
500.	5.87	8.86	8.71	.21	.02	.988	.999
354.	8.85	12.97	12.81	1.05	.69	.959	.975
250.	11.25	16.07	14.68	2.12	4.18	.935	.879
177.	13.24	16.24	14.28	7.56	11.09	.803	.727
125.	8.06	7.15	7.07	9.78	10.10	.581	.591
88.	6.33	4.50	4.65	9.80	9.80	.465	.495
63.	5.79	3.39	3.76	10.33	9.98	.384	.437
44.	7.60	3.77	4.57	14.85	13.85	.325	.405
31.	3.01	1.32	1.73	6.21	5.64	.287	.388
22.	18.05	7.56	9.99	37.91	34.68	.274	.373
SFR	202.290	132.390	136.239	69.900	66.051		

MENU :

- 0 = STOP EXECUTION
- 1 = RESTART FROM SCRATCH
- 2 = RESTART WITH PRESENT DATA
- 3 = CHANGE EFFICIENCY MODEL TYPE
- 4 = CHANGE OPTIMIZATION ALGORITHM
- 5 = CHANGE CRITERION TYPE
- 6 = CHANGE D50C,M,RF% ESTIMATES

COMMAND : 0

PRESENT DATA ARE RECORDED ON FILE TAPE3

STOP
041200 MAXIMUM EXECUTION FL.
1.212 CP SECONDS EXECUTION TIME.

4. REFERENCES

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