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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 5.1 Unit Models (Part B)

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The SPOC Manual

Chapter 5.1 Unit Models (Part B)

Unit Models and FORTRAN Simulators of Ore and Coal Process Equipment: Classification and Coal Processing

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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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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

Specific mathematical models of classification and coal processing equipment are described. Constraints and limitations are discussed for the following models: rotary breaker, a general coal crusher model, four screen models (Karra, Whiten, Valliant, and a sieve bend model), a hydrocyclone model, a gravity classifier model, and a specific gravity separator model. For each FORTRAN program, a small driver and test data are provided.

RÉSUMÉ

Ce chapitre décrit les modèles mathématiques d'unités de classification et de traitement du charbon. Le domaine de validité de chaque modèle et les limites physiques des unités y sont aussi décrits. Les modèles mathématiques des unités suivantes ont été programmés en FORTRAN en vue de leur utilisation dans un simulateur de circuit: trommel concasseur, concasseur de charbon, cribles (selon Karra, Whiten, Valliant et tamis DSM), hydrocyclones, classificateurs par sédimentation (à vis, à rateau), classificateurs à milieu dense. Chaque simulateur en FORTRAN comprend un programme principal, un programme d'impression de résultats et des données d'essai.

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. PROGRAM IDENTIFICATION

Program Titles:

ROTARY Breaker (coal)
VAlliant **CR**u**SH**er (coal)
Karra coarse **SCR**ee**N**
Whiten coarse **SCR**ee**N**
Valliant coarse **SCR**ee**N**
Sieve **BEND**
Hydro**C**ycl**ONE**
Gravity **CLASS**ifier
Specific **G**ravity **SEP**arator

Program Code Names:

ROTARY
VACRSH
KSCRN
WSCRN
VSCRN
BEND
HCONE
GCLASS
SGSEP

Program Writers:

L. Plitt, B. Flintoff, B. Snider, and R. Smith, Dept. of Mineral Engineering, University of Alberta, Edmonton, T6G 2G6.

Date:

March 1981.

Updates:

These are 1981 renditions of unit models as found in the literature, or modified as documented. Later improvements will lead to documented updates.

Source Language:

FORTRAN extended 4.6. Complying with American National Standards Institute FORTRAN X3.9 – 1966 and implemented on the EMR CDC CYBER computer.

Availability:

Complete program listing is available from:

Technology Information Division,
CANMET,
Energy, Mines and Resources Canada,
555 Booth Street,
Ottawa, Ontario,
K1A 0G1.

Basis for Models:

ROTARY:
The rotary breaker model chosen for implementation in SPOC, is that of Valliant (1).

VACRSH:
The Valliant crusher model as incorporated in Gottfried's (1) and later in Battelle's (2) coal preparation plant simulation packages was chosen.

KSCRN:
The Karra Screen model was adopted (3).

WSCRN:
The chosen model of screening was developed by Whiten (4) and further expanded by Walter and Whiten (5).

VSCRN:
The chosen model of screening was developed by Valliant (1) for Gottfried's original coal preparation plant simulator. It was later enhanced in the Battelle package (2).

BEND:
The chosen sieve bend (wedge wire) screen is that outlined by Lynch in his book (6).

HCONE:
The chosen model is based on the hydrocyclone study by Plitt (7).

GCLASS:
The gravity classification model implemented in SPOC is a combination of some of the concepts of Schubert and Nesse (8) with the basic design procedures outlined by Roberts and Fitch (9).

SGSEP:
This specific gravity separation model is very simply the partition curve used in the industry for many years.

2. ENGINEERING DOCUMENTATION

2.1 NARRATIVE DESCRIPTION

2.1.1 General Introduction

2.1.1.1 Objectives

The objective of this portion of the SPOC project was to produce validated simulation modules, written in FORTRAN source code, for the following unit operations:

- — hydrocycloning
- — gravity classification (rake, spiral)
- — coarse screening
- — fine screening (sieve bend)
- — coal comminution (rotary breakers, crushers)
- — specific gravity separation (dense medium vessels/cyclones; jigs, tables, automedium cyclones).

In addition to well-documented source code, written documentation was required to more effectively transfer the technology associated with the model development to the user.

2.1.1.2 Simulation modules

The simulation modules which have been coded and documented are summarized in Table 1.

Table 1 — SPOC simulation modules

Unit operation	Simulation module
Rotary breaker (Coal)	ROTARY
Crusher (Coal)	VACRSH
Coarse screen (Karra)	KSCRN
Coarse screen (Whiten)	WSCRN
Coarse screen (Valliant)	VSCRN
Sieve bend	BEND
Hydrocyclone	HCONE
Gravity classifier	GCLASS
Specific gravity separator	SGSEP

For background information, the reader is referred to the written documentation; for instructions in usage, reference should be made to the source code documentation.

2.1.2 The Uniformity Assumption

In many of the calculations which are required for solution of the mathematical model of a process unit, an assumption is made about the distribution of material within narrow size and/or specific gravity intervals. More often than not, the uniformity assumption has been invoked to simplify the computations. Since the authors have never seen any assessment of the validity of this, or any other of the more common assumptions, a separate study was done in this area. The results show that the uniformity assumption appears to give quite a reasonable approximation to material distribution (Appendix A).

2.1.3 Coal Comminution

The mathematical modelling of comminution operations in coal preparation applications has been largely untouched until recently. Even with the latest developments, however, there exists an interface problem with the separation unit operations because of the absence of a suitable liberation model (viz. typical base metal comminution/flotation circuits). While, in general, the same principles are operative in both mineral and coal dressing comminution circuits, the relative frequency of occurrence in plant flowsheets is very much different. Comminution in coal preparation receives much less interest since physical separation (i.e., specific gravity difference) does not require fine particulates in the feed. In fact, process efficiency is maximized at the coarser sizes, providing the material can be adequately handled. This, then, is the most frequent application, i.e., primary crushing, which reduces the preparation plant feed to an optimal size with respect to handling, the separation circuit design, and buyer specifications.

To a lesser extent one does find crushers embedded in the preparation plant flowsheet. These operate either in the role of product finishing, with respect to size, or crushing middlings streams for liberation purposes.

Comminution operations are invariably open circuit in the classical sense. However, units such as the rotary breaker ensure a maximum product particle size by virtue of their design.

The unit operations most frequently encountered in Canadian coal preparation applications include:

- — the rotary breaker
- — the roll(s) crusher.

Mathematical models for these units have been taken from the literature and coded as simulation modules for SPOC. Figures 1 and 2 are schematic illustrations of these two devices.

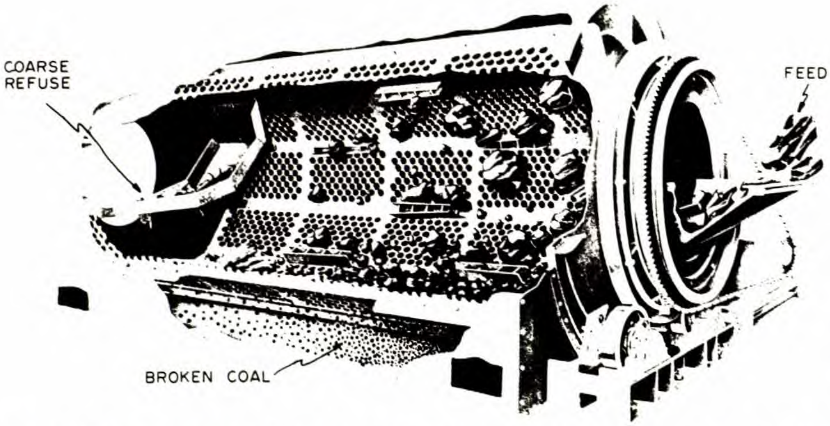


Fig. 1 – Rotary breaker (Courtesy of Pennsylvania Crusher Corp., Broomall, Pa.)

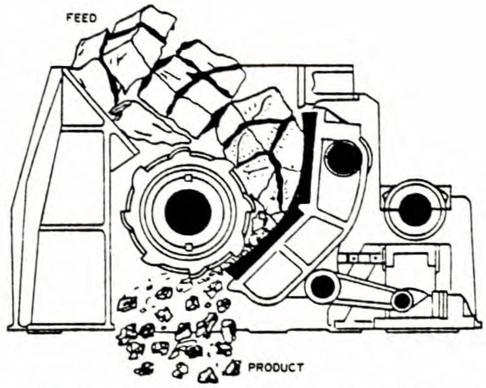


Fig. 2 – Toothed single roll crusher (Courtesy of Pennsylvania Crusher Corp., Broomall, Pa.)

2.1.4 Particle Size and Density Separation

2.1.4.1 Introduction

Many of the unit operations which are incorporated in both mineral processing and coal preparation circuits, are devices which exploit the physical differences between particles, to effect the solid–solid separation. Typically this would include particle size, particle shape, particle gravity, and combinations thereof.

Particle size is important in both coal and mineral dressing operations, because it is an inferential measurement of liberation. Further, the separation efficiencies of these, as well as other classes of separation unit operations, are strongly dependent upon particle size with respect to the gravitational/drag forces that are operative in slurry systems. In either of these industrial settings, it is not unusual to find size classification devices making separations anywhere in the range of about 50000 to 50 μm, either in a wet or dry environment. This great difference in operating duty has resulted in a variety of size classification units being developed, each of which is *optimal* for some size range. Very generally, it is possible to categorize these units as:

1. Coarse Screens: Wet or dry operation with aperture dimension in the range >3000 μm.
2. Fine Screens: Usually wet operation with aperture dimension in the order of 300 to 1000 μm.
3. Hydraulic Classifiers: Wet operation which affects particle size separation on the basis of differential setting velocities. The effective separation size with these devices varies in the range of about 20 to 500 μm.

Considerable effort has been made in the mineral processing industry to mathematically characterize these unit operations, both for reasons of process analysis as well as digital simulation studies.

Particle specific gravity is also important in both coal and mineral dressing operations since different minerals/rock types will have different specific gravities. If the difference in specific gravity between the desired and the undesired minerals/rock types is large enough, a separation may be made on this basis. (The magnitude of the density difference required for efficient separation is very much a function of the particular unit operation chosen for the job.) Outside of iron ore processing, this class of separation device has been largely supplanted by froth flotation in the mineral processing area. However, in coal preparation, most washed coal is prepared in this manner.

2.1.4.2 Coarse particle screening

Coarse screening refers to particle size separations at sizes nominally greater than 3000 μm. Generally, these unit operations consist of a single/double inclined vibrating screen deck which can treat essentially-dry or wet feed. Further, the aperture pattern on the screen deck can vary considerably depending upon the application.

The mathematical modelling of coarse screening in mineral processing has been done in conjunction with, or in support of, digital simulation studies of crushing circuits. This represents the principal industrial application of these devices in this field.

The mathematical modelling of coarse screening in coal preparation has also been done in support of digital simulation studies, but not nearly to the same extent. These screens are used to sort the coal prior to cleaning, for it has been well established that particular separation units achieve optimal efficiency on certain size ranges of particulate material.

A schematic representation on the coarse screen is provided in Figure 3.

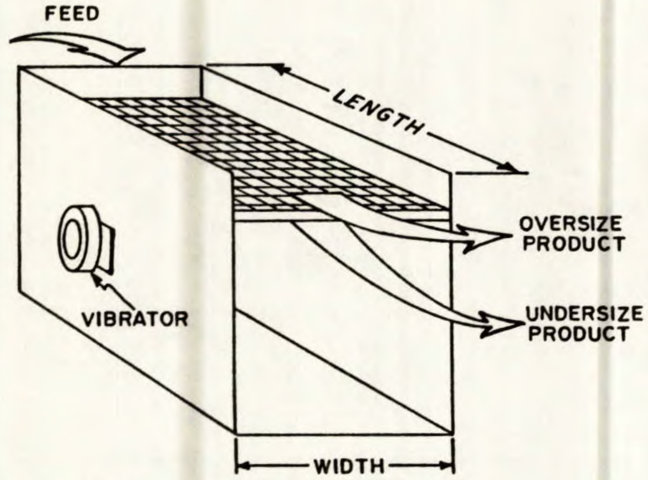


Fig. 3 – Schematic of a single deck screen

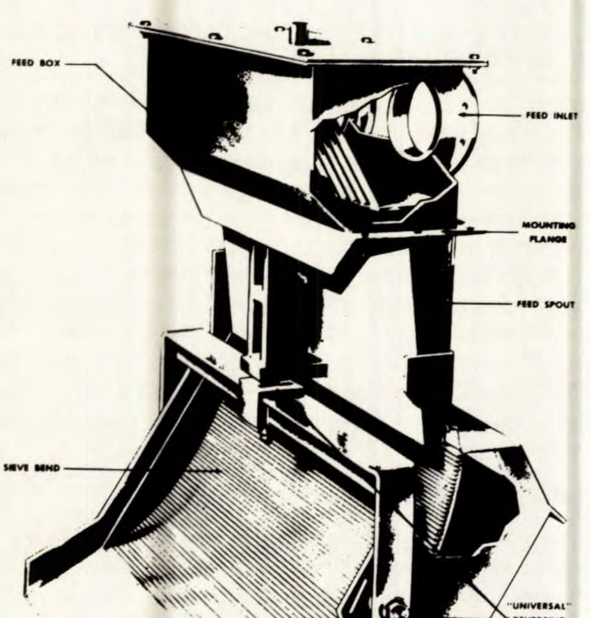


Fig. 4 – Cutaway view of a sieve bend (Courtesy of Heyl & Patterson, Pittsburgh, Pa.)

2.1.4.3 Fine particle screening

Fine screening refers to screening at sizes below that which can effectively be achieved with conventional vibrating screens, e.g., approximately 1000 μm.

Size separations below 300 μm are usually carried out by classifiers. In some instances, the mineral density alters the separation size in an undesirable manner. In these cases, screening can be used to great advantage since it separates on the basis of size alone.

Although successful applications of special high-speed vibrating screens down to sizes of 45 μm have recently been reported (10), the most common fine screen in use today is the sieve bend. This screen was first developed by the Dutch State Mines in 1953 for coal separation. It has since found application in other processing fields. Special designs of the sieve bend that employ rapping devices to reduce blinding permit screening down to 45 μm (11). A typical sieve bend is shown in Figure 4.

2.1.4.4 Classification

In mineral processing, classification refers to processes which carry out a solid–solid separation based upon the differing particle settling velocities in a fluid medium (usually water). If the solids are of uniform density, then the separation is made entirely upon particle size and/or shape. Classification processes are generally applied where the required size of separation is too fine to be efficiently carried out by screening (usually below 600 μm although in some cases screens are being used down to 45 μm).

In mineral and coal processing plants, classifiers are normally used in one of the following roles:

- classification in closed-circuit grinding
- desliming
- preparation of feed to gravity separators.

The hydrocyclone is the most widely used classifier because of its many advantages such as low initial cost, low floor space requirements, and simplicity of operation, i.e., no moving parts. During the 1950's, the hydrocyclone classifier assumed dominance over the gravity classifiers. The range of separation achievable with a hydrocyclone varies from 5 μm (small diameter cyclones and dilute slurries) to 400 μm (large diameter cyclones with high per cent solid slurries). Cyclones range in size from 1 cm to over 100 cm in diameter. Although many minor variations in design exist, most hydrocyclone classifiers have the general configuration as outlined in Figure 5.

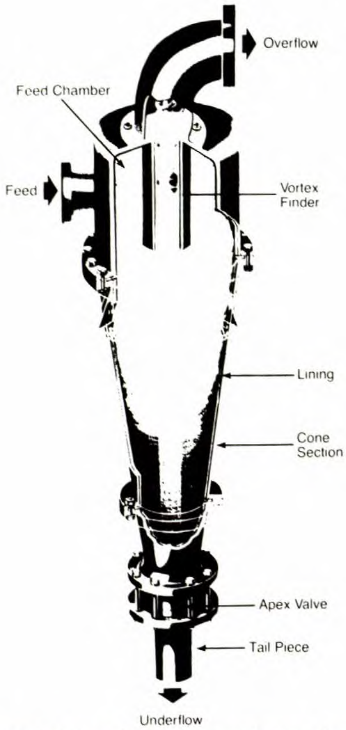


Fig. 5 – Cutaway view of a hydrocyclone classifier (Courtesy of Dorr-Oliver Canada Ltd., Orillia, Ont.)

Gravity classifiers are distinguished from the hydrocyclone classifiers because they use gravity instead of centrifugal forces to effect a separation. The lower limit of separation is therefore higher, i.e., 30 μm instead of 5 μm. Units which fall into this category are the spiral, rake, and cone classifiers. The main difference among these classifiers is the mechanism for coarse solids removal. In most flowsheets, gravity classifiers could be interchanged with the hydrocyclone as they perform essentially the same function, i.e., separation of particles with high settling velocities from those with low settling velocities. Some advantages of gravity classifiers over hydrocyclones are:

- lower unit energy consumption;
- greater flexibility for intermittent flows;
- higher solids content in coarse product stream with less fines bypass to coarse product;
- less susceptibility to blocking.

Figure 6 is a cutaway view of a rake classifier.

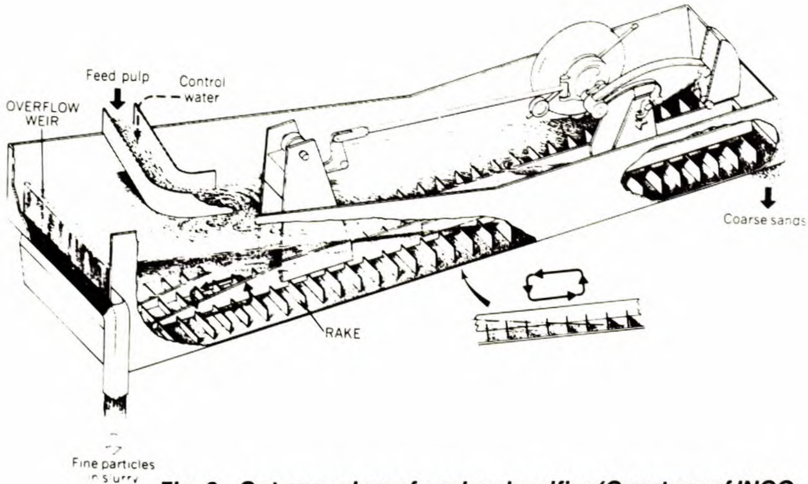


Fig. 6 – Cutaway view of a rake classifier (Courtesy of INCO Canada Ltd.)

2.1.4.5 Specific gravity separators

Specific gravity separation is a physical means of concentrating a valuable species from a mixture with a reject material by exploiting the differences in particulate specific gravity. Unit operations which embody this principle have been employed in mineral and coal dressing operations for many years. However, with the possible exception of iron ore processing, coal cleaning applications represent the major use of this technology in Canada. Given the projections for expansion in the Canadian coal industry over the next two decades (12,13), this disparity will grow even larger. It is for this reason that, while the simulation module developed for SPOC is applicable to other industries, it is essentially custom-designed for coal preparation, both in terms of its default database and the data structure.

There is a variety of equipment used in coal preparation plants which separate the organic matter from the mineral matter exploiting the difference in density. While dry cleaning is gaining interest with the prospect of preparing lower rank coals, virtually all cleaning is accomplished using wet methods. Again, while the simulation module is applicable for dry separations, the SPOC module is custom-designed for wet coal preparation applications.

In general, the wet methods for concentrating coal may be categorized according to the size of particulate material treated and subcategorized according to the fluid medium in which the separation takes place. Table 2 presents this general classification scheme which includes those unit operations which are currently used to wash Canadian coal.

Table 2 —A general classification of wet coal concentration methods*

Circuit	Dense medium	Water
Coarse	Vessel/Bath	Jig
Mid-size	Cyclone	Table
Fine	—	Automedium Cyclone

* Much of the fine (0.6 mm × 0 mm) western Canada metallurgical coal is prepared by froth flotation.

For more detail on the mechanical variants and operating characteristics of these units, the reader is referred to Leonard's text (14). Suffice to say at this time that the general approach to modelling these units is the same for all classes.

Unfortunately, from the point of view of SPOC, there exist large but proprietary databases, e.g., N.C.B.-U.K., which presumably contain the kind of information from which one might build more complete models. These would incorporate, in some manner, the effects of changes in both the feed stream properties as well as the equipment-operating parameters. However, given the information which was available to the authors, it is possible to report only on first-generation efforts in this area. Despite this rather strict limitation, these models can be of great value in digital simulation studies.

Figure 7 is a schematic of a dense-medium separation vessel illustrating the principles of operation.

2.2 METHOD OF SOLUTION

2.2.1 Rotary Breaker Model (ROTARY)

The mathematical modelling of rotary breakers in coal preparation has received relatively little attention. Valiant (1) was the first to propose a model for this unit operation. More recently, Austin (15) has apparently improved upon this model, in the sense that a more thorough investigation was carried out and a more mechanistically satisfying model evolved**. (Unfortunately, this model was not available to the author at the time of writing. However, it is recommended that it be considered for implementation at some future date.) There are two reasons why it is supposed that work in this area has been slow to progress, quite apart from the political/economic motivation which usually initiates studies of this type:

1. Rotary breakers are generally used as primary crushers, simply reducing the material to some maximum size which ensures both sufficient liberation and product handleability. Subsequent to the flowsheet design stage, changes in the operating parameters of the breaker are difficult to make and the operator, usually rightfully so, concerns himself with the optimal treatment of the breaker discharge. (In some cases, there arise geographical constraints where the breaker station is remotely located, further removing it from the influence and concern of the preparation plant.)

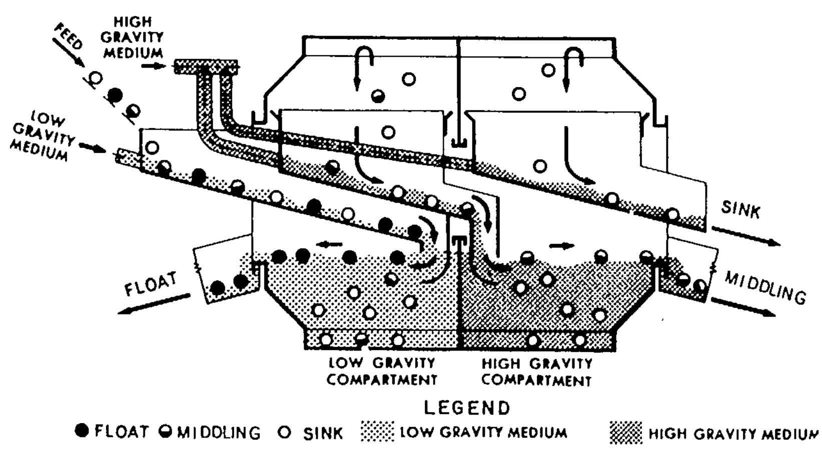


Fig. 7 – Schematic of a dense-medium separation vessel illustrating the principles of operation (Courtesy of Wemco Canada, Mississauga, Ont.)

***Personal communication with Dr. P.T. Luckie (July 1980) regarding an alternative model form for a rotary breaker.*

2. The nature of the material which a breaker must handle (i.e., ROM coal) presents a very difficult sampling problem because of particulate size. Weighing the practical difficulties of accurately sampling the unit at "representative" steady state, coupled with the complexity of developing a distributed parameter comminution model which includes liberation, greatly reduces the motivation to attack the problem.

The rotary breaker model of Valliant was chosen for implementation in SPOC. This was the only published model available at the time of writing. Considering the role of the rotary breaker in coal preparation and the potential difficulty of calibrating a more complex model, the simplicity of use provides a good argument for using this module as a first approximation.

Conceptually, Valliant's model of the rotary breaker supposes that the coal is processed serially in a number of tumbling events. Each tumbling event consists of coal breakage arising from the tumbling action, followed by screening, which accounts for fine particle passage through the drum apertures. The material which remains within the breaker after the combined breakage/screening is the feed to the next tumbling event, and so on.

In addition to the feed stream, the user needs to specify only three operating variables, namely:

- the breaker length in metres;
- the breaker diameter in metres;
- the breaker drum aperture size in micrometres.

From the breaker length, the number of tumbling events is computed. The breaker drum diameter is used to scale up the particle selection for breakage elements if the diameter exceeds some critical value. The drum aperture size determines the efficiency of the screening action.

The model accounts minimally for liberation by dividing the breaker feed stream into two parts, each of which is processed separately using the model. These two streams can be thought of as a coal stream and a rock stream. The rock stream is calculated by assuming that the differences in the mass flow of ash (not mineral matter) in the heaviest and second heaviest specific gravity intervals are essentially free of dilution rock. The mass flow of rock so obtained is said to assay 100% ash, as expected, but because beyond this restriction the data structure has no presupposed format, all other characteristics for the rock stream are assumed to have zero values. (For calorific value, this seems entirely reasonable, but the assumption is in question say for pyritic sulphur.) The user should be aware of this assumption particularly with respect to a significant mass flow of this rock material.

The breakage function elements are computed in the regular manner. However, the selection-for-breakage function elements are unique in the sense that they do not exhibit particle size dependence. In essence, Valliant assumes an equal probability of breakage for all particles within the breaker. (However, he does mention that this is an area for potential improvement.) While the selection function elements are not size dependent, they are assumed to decrease as the number of tumbling events processed (e.g., residence time) increases, ostensibly to reflect the work hardening of brittle materials. The coal and rock streams have different selection function elements, but assume the same form for the cumulative breakage function. Other than this minimal accounting, selection and breakage function values are assumed to be independent of particle specific gravity. (That is, the model assumes lumped selection and breakage functions with respect to particle specific gravity.)

The effects of feed stream characteristics, i.e., size composition, mass flow rate, etc. are excluded from consideration in the model as are the equipment operating parameters, i.e., speed rotation, angle of inclination, . . . Further, while empirical capacity and power draft formulae (14) exist in the literature, they have not been included in the SPOC simulation module.

2.2.1.1 Mathematical derivation

The general form of the mathematical models, which are used as a basis for the rotary breaker simulation module, includes the comminution model originally proposed by Callcott and Broadbent (16) and the screen model proposed by Valliant (see this model description in this chapter). Mathematically, and in vector-matrix notation,

$$\hat{p}_i = (B\,S_i + I - S_i)\,\hat{f}_i \qquad \text{Eq 1}$$

where:

- $\hat{p}_i$ = breakage product solids mass flow on size vector for the i^{th} tumbling event.
- B = lower triangular breakage matrix.
- S_i = diagonal selection for breakage matrix for the i^{th} tumbling event.
- I = diagonal identity matrix.
- $\hat{f}_i$ = feed mass flow on size vector to the i^{th} tumbling event.

and,

$$\hat{m}_i = (I - E)\,\hat{p}_i \qquad \text{Eq 2}$$

$$\hat{f}_{i+1} = E\,\hat{p}_i \qquad \text{Eq 3}$$

where:

$\hat{m}_i$ = breakage undersize solids mass flow on size vector for the i^{th} tumbling event.

E = diagonal screening action matrix.

Note that for convenience of symbolism in the development, the input/output streams are unidimensional in size.

The cumulative breaker coal product (i.e., undersize, fine) is then computed as the sum of the products over the N tumbling events,

$$\hat{M}_N = \sum_{i=1}^{N} \hat{m}_i \qquad \text{Eq 4}$$

where:

$\hat{M}_N$ = cumulative breaker undersize mass flow on size vector.

And, while the breaker refuse could be computed as,

$$\hat{F}_N = \left[\prod_{i=1}^{N} (E\,D_i)\,\hat{f}_1\right] \qquad \text{Eq 5}$$

where:

$\hat{F}_N$ = cumulative breaker oversize mass flow on size vector and $D_i = (B\,S_i + I - S_i)$,

practically, it is obtained from Equation 3 on the solution for the final tumbling event.

The maximum number of tumbling events, N_c, which any coal particle might undergo is computed as,

$$N_c = \left|\frac{L}{0.3962}\right| \qquad \text{Eq 6}$$

where:

N_c = maximum number of tumbling events for a coal stream particle.

L = breaker length in metres.

In the module code, N_c is taken as the integer value of this expression. The rock stream, on the other hand, is assumed to undergo only one tumbling event, i.e.,

$$N_r = 1 \qquad \text{Eq 7}$$

where:

N_r = maximum number of tumbling events for a rock stream particle.

The selection for breakage elements are computed in the following manner. For coal, all of the elements on the diagonal of S_i, say s_{jj}, have the same numerical value depending only upon the value of i (the tumbling event), and perhaps the value of the scale factor, f.

$$s_{jj} = \begin{cases} 0.2f & i \le 12 \\ 0.08f & 12 < i \le 24 \\ 0.06f & 24 < i \le 36 \\ 0.05f & 36 < i \end{cases} \quad i = 1,\dots,N \qquad \text{Eq 8}$$

where:

s_{jj} is on the diagonal of S_i and,

$$f = \begin{cases} 1 & D \le 2.438 \\ \dfrac{D}{2.438} & 2.438 < D \end{cases} \qquad \text{Eq 9}$$

where:

f = the selection function scale factor.

D = the breaker diameter in metres.

Similarly, for the rock stream,

$$s_{jj} = \begin{cases} 0.005f & i = 1 \\ 0.0 & 1 < i \end{cases} \quad 1,\dots,N \qquad \text{Eq 10}$$

where:

s_{jj} is on the diagonal of S_i.

The elements of the breakage matrix are computed from a cumulative breakage function assuming normalizability. That is, particles all break in an identical manner, independent of the parent particle size. Mathematically,

$$B_{ij} = \left[\frac{1 - \exp(-\bar{d}_i/\bar{d}_j)}{1 - \exp(-1)}\right] ; \; i = j+1, j+2, \dots \qquad \text{Eq 11}$$

where:

B_{ij} = cumulative fraction of material broken from parent interval j which passes daughter interval i.

$\bar{d}_j$ = arithmetic mean (characteristic) size of the j^{th} interval which is bounded by sizes d_j and d_{j+1}.

$$\bar{d}_j = \left[\frac{d_j + d_{j+1}}{2}\right]$$

The reader may recognize the functional form of the cumulative breakage function as Callcott and Broadbent's *general distribution*. The discretized elements required to generate B are calculated as,

$$b_{ij} = B_{i-1j} - B_{ij};\ i = j + 1, j + 2,... \qquad \text{Eq 12}$$

where:

b_{ij} = the fraction of material broken from parent interval j which reports to daughter interval i. (N.B. $B_{jj} = 1.0$)

Note that the implication of Equation 12 is that all of the material which is selected for breakage in parent interval j, is broken to daughters which are finer than j ($b_{jj} = 0$).

Finally, the elements of the diagonal screening matrix, E, are computed using Valliant's screening model.

$$e_{jj} = \begin{cases} 1.0 & d_{j+1} \geq h \\ h \dfrac{[\exp(-A(1-d_j/h)) - \exp(-A(1-d_{j+1}/h))]}{A(d_j - d_{j+1})} & d_j \leq h \end{cases} \qquad \text{Eq 13}$$

where:

e_{jj} is on the diagonal of E.
h = the breaker aperture size.
A = screen separation strength.

$$A = \begin{bmatrix} 40 & h \leq 177800\ \mu m \\ 50 & 177800\ \mu m < h \end{bmatrix} \qquad \text{Eq 14}$$

The subtleties of implementing Equation 13, if h is constrained within a size interval, are described in the Valliant screen model documentation. Given that the elements of B and E are invariant and that the elements of S_i can be computed for any tumbling event, i, for both the coal and the rock streams, the simulation calculations can be performed in a serial manner. In essence, all of the characteristics as well as the primary elements are converted to equivalent mass flow rates, as opposed to their standard assay format. This is necessary since the breaker is a two-product transformation device and is unique in that sense. For example, the mass flow rate of characteristic 2 in the feed is computed as,

$$\hat{f}_{1ij3} = F\, f_{ij1}\, f_{ij3} \qquad \text{Eq 15}$$

where:

$\hat{f}_{1ij3}$ = the equivalent mass flow of characteristic 2 in the breaker feed (for either stream).
F = mass flow of solids in feed.
f_{ij1} = primary element in feed solids array.
f_{ij3} = characteristic assay in feed array.

Hence the breakage products for the first tumbling event are computed as,

Primary Element

$$\hat{p}_{1ij1} = d_{ii}\,\hat{f}_{1ij1} + \sum_{m=1}^{i-1} d_{im}\,\hat{f}_{1mj1};\ j = 1,...,NG;\ i = 1,...,NS \qquad \text{Eq 16}$$

where:

$\hat{p}_{1ij1}$ = the mass flow of primary element in the breakage products.
NG = the number of specific gravity intervals in the solids arrays.
NS = the number of size intervals.

Characteristic

$$\hat{p}_{lijk} = d_{ii}\,\hat{f}_{1ijk} + \sum_{m=1}^{i-l} d_{im}\,\hat{f}_{1mjk};\ k = 2,...,NC;\ j = 1,...,NG;\ i = 1,...,NS \qquad \text{Eq 17}$$

where:

$\hat{p}_{1ijk}$ = the mass flow of characteristic (k-1) in the breakage products.
NC = the total number of characteristics (including the primary element) in the solids array.
d_{ij} = an element in the lower triangular matrix D_1.

(D_1 is referred to as the transformation matrix for the first tumbling event since it describes, in a mathematical sense, the transformation of feed to product.)

The products of screening on the first tumbling event produce,

$$\hat{m}_{1ijk} = (1 - e_{ii})\,\hat{p}_{1ijk};\quad k = 1,...,NC;\ j = 1,...,NG;\ i = 1,...,NS \qquad \text{Eq 18}$$

where:

$\hat{m}_{1ijk}$ = the mass flow in the screening products, and,

$$\hat{f}_{2ijk} = e_{ii}\,\hat{p}_{1ijk};\quad k = 1,...,NC;\ j = 1,...,NG;\ i = 1,...,NS \qquad \text{Eq 19}$$

where:

$\hat{f}_{2ijk}$ = the equivalent mass flow in the feed to the second tumbling event.

This sequence of computations is done N_c and N_r times for the coal and rock feed streams, respectively. The ultimate breaker products are computed as the sum of the products from each feed species and, ultimately, the mass flow rates are reconverted to characteristic assays.

The breaker model has been modified to account for water in the feed. However, it is assumed that this will be the bed moisture of the coal since the rotary breaker operates on essentially dry feed. Under these conditions, all of the water in the feed is assumed to report to the coal (fine) breaker product.

2.2.1.2 Constraints

The incomplete development of the model precludes the incorporation of explicit constraints. The user is directed to refer to published and/or vendor literature on the rotary breaker unit being simulated, with a view to assessing the simulation results.

2.2.1.3 Limitations

Clearly, one of the chief limitations of the model is its inability to account for liberation which occurs in comminution.

Other limitations include the inability to account for changes in comminution behaviour as a result of changes in equipment operating parameters and/or feed stream properties. Further, the use of essentially lumped breakage and selection functions coupled with the size independence of the latter, may be dangerous, particularly if the gravity and size distributions are much different from those on which the model was derived.

The compromise in using this model is accuracy versus simplicity. Since Valliant didn't publish any of the experimental data against which the model was presumably tested, its accuracy is purely a matter of speculation. However, and with regard to the role which rotary breakers play in coal preparation simulation, this seems quite a logical choice for a SPOC module, primarily on the basis of its simplicity.

Due to the model structure, the variations of the breaker length affect the result through the variations of the integer part of the ratio L/0.3962 (i.e., $0.3962 \leq L < 0.7924$; $0.7924 \leq L < 2.3772$, etc. are the only ranges of sizes within which the length parameter has an effect).

Similarly, the breaker diameter is used to modify a scale factor of the selection function as per Equation 9. All values of D smaller or equal to 2.438 are therefore considered as identical in the model.

2.2.2 Coal Crusher Model (VACRSH)

The mathematical modelling of crushers in coal preparation has received relatively little attention. Valliant (1) was apparently the first to propose a *general* model of coal crushing. More recently, Austin et al. (17) have published the results of a modelling exercise for the single roll crusher in a coal comminution application. The model form which evolved in Austin's work is more mechanistically satisfying than Valliant's model. However, its generality remains unproven and the parameterization process requires considerable experimental and computational effort. Other crusher models which generally fall into the same class as Austin's, with respect to form, have been developed in the mineral processing literature for use in industrial crushing plant simulation. Whiten's model (4), which was subsequently modified and used by Mular (18), is a potential candidate form for evaluation in future testwork.

Crushers in coal preparation circuits are generally used for one of two purposes:

1. Reduction of the coarse clean coal product size to meet buyer specification, e.g., Kaiser (19), Fording (20).
2. Crushing of coarse coal middlings to liberate the *organic fraction* from the mineral matter, e.g., Luscar-Sterco (21).

Of the two, the second is considered to be the most important from a process economics point of view. However, in the absence of a suitable liberation model, it is impossible to accurately simulate such an operation. Efforts are apparently underway* to develop a liberation model, but, until these bear fruit, crusher models are simply able to simulate particle size reduction. In the overall preparation plant simulation calculations, this has a secondary effect on washing efficiency since the washing unit partition curves are sensitive to feed size distribution.

In view of the absence of a liberation model, it was decided that, for the purposes of SPOC, a relatively simple model requiring minimal user calibration would be implemented. (This leaves the user with more time to devote to the separation units, which are the most important in an economic sense.) Valliant's model, which was incorporated in Gottfried's (1) and later in Battelle's (2) coal preparation plant simulation packages, was chosen.

Valliant's model is said to be capable of simulating the following crushing units:

— gyratory and jaw crushers

— single roll crushers

— multiple roll crushers

— cage mill crushers

operating in either a primary or secondary mode. In addition, a set of default breakage parameters are provided such that the user input to the module is minimal, defining only the crusher setting, a *zone constant*, the crusher type, and its mode of operation.

**Personal communication with Dr. P.T. Luckie (July 1980) regarding an integrated rotary breaker/liberation model for coal.*

Conceptually, Valliant's model is of a somewhat different form than Whiten's (Mular's); however, it does possess some strong similarities. For example, Valliant's model appears to recognize the complexity of the breakage function and, indeed, uses a two-part structure in a manner somewhat analogous to Whiten. Further, the selection (or classification, according to other authors) function values are assumed to have specific functional forms, relative to particle size. Finally, Valliant identifies three crushing zones for which the selection function values are computed differently, again in a manner similar to Whiten.

In essence, Valliant's model identifies three crushing zones within which coal particle breakage is computed in a different manner. The model neglects the effect of particle specific gravity on both selection for breakage as well as breakage. (That is, the model assumes lumped selection and breakage functions with respect to particle specific gravity.) Zone 1 material is the very coarse fraction of the feed which is completely transformed to finer (zone 2,3) particles in the crushing operation. The zone 2 material consists of those particles which are coarser than, but in the neighbourhood of, the crusher setting. Particles in this zone have a high probability of selection for breakage, typically 0.85, and that fraction of a size interval which is selected, is completely distributed to the finer size intervals. Zone 3 material is defined as those particles which are smaller than the crusher setting. In this case, the selection function values decrease exponentially with decreasing particle size; the actual rate of decrease is functionally dependent upon the operating mode. Unlike other crusher models, Valliant's formulation contains no empirical relationships which correlate crusher power draught, selection and breakage function values, etc., to both operating conditions and feed stream properties.

2.2.2.1 Mathematical derivation

The general form of the mathematical model which is used as a basis for the crusher module was originally proposed by Callcott and Broadbent (16). Mathematically,

$$p = (B\,S + I - S)\,f \qquad \text{Eq 20}$$

where:

- p = product frequency on size vector
- f = feed frequency on size vector
- B = lower triangular breakage matrix
- S = diagonal selection matrix
- I = diagonal identity matrix.

(Note that for convenience of symbolism in the development, the input/output streams are assumed unidimensional in size only.)

In this development the term selection matrix (function) is retained (viz. Austin's work); however, the reader can consider it to be a classification matrix (function) if preferred (viz. Whiten and Mular). For convenience, the matrix in the parentheses above will be written as,

$$D = (B\,S + I - S) \qquad \text{Eq 21}$$

and referred to as a *transformation matrix*, since it describes, in a mathematical sense, the means by which the crusher transforms the feed into product.

Before further development of the model, it is necessary to define the crushing zones and relate both selection and breakage to them. According to Valliant, zone 1 contains all particles which are larger than some constant (invariably taken to be 1.7) multiplied by the crusher setting. Zone 2 contains those particles which are finer than the lower bound of zone 1 but larger than the crusher setting. Finally, zone 3 contains particles finer than the crusher setting. Thus, for a particle of size d, the zone to which it belongs is established as,

$$\left\{\begin{array}{ll} \text{Zone 1} & 1.7S_o \le d \\ \text{Zone 2} & S_o \le d < 1.7S_o \\ \text{Zone 3} & d < S_o \end{array}\right\} \qquad \text{Eq 22}$$

where:

- S_o = the crusher setting
- d = the particle size.

In a manner similar to Whiten and Austin, Valliant assumed a functional form for calculating the elements of the selection matrix. However, while Whiten and Austin use parametric equations which are fitted to the experimental data, Valliant assumes a form which is entirely independent of measurement and crusher type. Quite simply, the only decision variable affecting the computation is the operating mode. Mathematically,

$$s_{ii} = \left\{\begin{array}{ll} 1.0 & (d_i, d_{i+1}) \text{ in Zone 1} \\ 0.85 & (d_i, d_{i+1}) \text{ in Zone 2} \\ \dfrac{.85S_o\left(e^{-A(1-d_i/S_o)} - e^{-A(1-d_{i+1}/S_o)}\right)}{A(d_i - d_{i+1})} & (d_i, d_{i+1}) \text{ in Zone 3} \end{array}\right\} \qquad \text{Eq 23}$$

where:

- s_{ii} = selection function for size interval i.
- d_i, d_{i+1} = upper and lower size bounds for interval i.
- A = separation strength of the crusher.

$$A = \left\{\begin{array}{l} 2 \text{ for secondary crushers} \\ 8 \text{ for primary crushers} \end{array}\right\}$$

The reader may recognize the functional form for zone 3 particles as Valliant's screen model (described later in this chapter). The separation strength, *A* is given a lower numerical value for secondary crushers because operation in this mode is *observed* to have a larger effect on zone 3 particle breakage.

The elements of the breakage matrix are computed from cumulative breakage functions which are assumed to be normalizable. That is, particles which correspond to a particular breakage function, break in an identical manner, independent of the parent particle size. Mathematically,

$$B_{ij} = \begin{cases} B^{u}_{ij} & (d_j, d_{j+1}) \text{ in Zone 1} \\ \left[\dfrac{1-\exp(-\bar{d}_i/\bar{d}_j)}{1-\exp(-1)}\right] & (d_j, d_{j+1}) \text{ in Zone 2} \\ & \text{or Zone 3} \end{cases} \qquad \text{Eq 24}$$

where:

B_{ij} = cumulative fraction of material broken from parent interval j which passes daughter interval i.

$\bar{d}_j$ = arithmetic mean (characteristic) size of the j^{th} interval.

$$\text{i.e., } \bar{d}_j = \left[\frac{d_j + d_{j+1}}{2}\right]$$

B^{u}_{ij} = unit dependent cumulative breakage function as determined by Valliant.

The reader may recognize the functional form for the zone 2 and zone 3 cumulative breakage function as Callcott and Broadbent's *general distribution.* Valliant has provided default values for the unit dependent cumulative breakage functions, and they are presented in Table 3.

Employing the data of Table 3 and a linear interpolation subroutine, the discretized breakage elements required for B are calculated as,

$$b_{ij} = \hat{B}_{i-1j} - \hat{B}_{ij} \qquad \text{Eq 25}$$

with $\hat{B}_{jj} = 1$ by definition ($b_{jj} = 0$)

where:

b_{ij} = the fraction of material which breaks from parent interval j to the daughter interval i.

$\hat{B}_{ij}$ = the appropriate cumulative breakage function as specified in Equation 24.

Unfortunately, unlike the other crusher models, Valliant's implementation allows for an extra degree of computational complexity. That is, values of S_o and $1.7S_o$ which do not coincide with size interval boundaries have the potential of creating two new size fractions, while redefining the limits on one or two of the others. Consider the case where both $1.7S_o$ and S_o are contained within the k^{th} size interval. (The simpler cases where S_o and $1.7S_o$ lie in different intervals is handled in an analogous manner.) This is illustrated schematically in Figure 8.

Table 3 — Crusher dependent cumulative breakage functions from Vol. 1, Battelle documentation

Size ratio	General distribution	Multiple roll crusher	Gyratory/ jaw crusher	Single roll crusher	Primary cage mill crusher
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
.8308	.8927	.9500	.9500	.9600	.8400
.5882	.7035	.8500	.8500	.7900	.5000
.4176	.5400	.6500	.7000	.4500	.3200
.2065	.2952	.3500	.3500	.2000	.1500
.1041	.1564	.2200	.2000	.1000	.0520
.0522	.0805	.1400	.1900	.0500	.0190
.0368	.0572	.1100	.1700	.0300	.0110
.0260	.0406	.0900	.1200	.0200	.0066
.0131	.0206	.0300	.0800	.0000	.0020
.0000	.0000	.0000	.0000	.0000	.0000

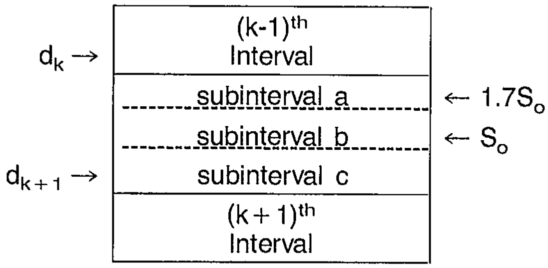


Fig. 8 – Interval partitioning by the zone delimiters ($1.7S_o$ and S_o)

The result of partitioning is to create three size intervals in place of one, where subinterval a is contained in zone 1, subinterval b in zone 2, and subinterval c is contained in zone 3. Now, the assumption is that material which breaks from parent interval k will not report to this interval (i.e., products to either of subintervals b or c, etc.). Assuming uniformity, the weight distribution in the subintervals is computed as,

$$f_a = \left[\frac{d_k - 1.7S_o}{d_k - d_{k+1}}\right] \qquad \text{Eq 26}$$

$$f_b = \left[\frac{1.7S_o - S_o}{d_k - d_{k+1}}\right] \qquad \text{Eq 27}$$

$$f_c = \left[\frac{S_o - d_{k+1}}{d_k - d_{k+1}}\right] \qquad \text{Eq 28}$$

where:

f_a,f_b, and f_c are the weight distribution factors for the subintervals, and

$$f_a + f_b + f_c = 1$$

From Equation 23, the selection matrix elements are given as,

$$s_a = 1$$

$$s_b = 0.85$$

$$s_c = \left[\frac{.85S_o\ [1 - e^{-A(1-d_{k+1}/S_o)}]}{A(S_o - d_{k+1})}\right]$$

Thus the diagonal element in the transformation matrix D would be computed as,

$$d_{kk} = f_a(1 - s_a) + f_b(1 - s_b) + f_c(1 - s_c) \qquad \text{Eq 29}$$

and the subdiagonal elements are computed as,

$$d_{ik} = f_a s_a b_{ia} + f_b s_b b_{ib} + f_c s_c b_{ic}$$
$$i = k + 1, k + 2, \ldots \qquad \text{Eq 30}$$

where the breakage elements are obtained using the data of Table 3 and a linear interpolation subroutine. For example, the characteristic size of subinterval a is,

$$\bar{d}_a = \left[\frac{d_k + 1.7S_o}{2}\right]$$

and passing the size ratios,

$$\bar{d}_{i-1}/\bar{d}_a \text{ and } \bar{d}_i/\bar{d}_a$$

provides values for,

$$B^u_{i-1\ a} \text{ and } B^u_{i\ a}$$

which, when substituted into Equation 25 yields b_{ia}. Despite the rather *messy* algebra, the method of solution is relatively straightforward.

Having laid the groundwork, it is now possible to look at the method of implementation. For the sake of an example, assume that m of the size fractions are fully contained in zone 1 (i.e., $d_{m+1} > 1.7S_o$). Under this assumption, Figure 9 is a schematic illustration of Valliant's model.

$$f \rightarrow \left[D_1^1\right] \rightarrow \left[D_2^1\right] \rightarrow \left[\ \ldots\ \right] \rightarrow \left[D_m^1\right] \rightarrow \left[D^{23}\right] \rightarrow p \rightarrow$$

$$\text{i.e., } p = \left[D^{23} \prod_{i=1}^{m} D_i^1\right] f$$

Fig. 9 – A schematic illustration of Valliant's crusher model under a certain set of size conditions

The m separate crushing stages for the zone 1 particles have the effect of eliminating all of this size material from the product stream. The transformation matrix for any of these stages is simply the identity matrix with the exception that the appropriate column has zero on the diagonal and b_{ij}; $i = j + 1, \ldots$; $j = 1, \ldots, m$ below it. It is possible to define two transformation matrices,

$D^1 = D_m^1 D_{m-1}^1 \ldots D_2^1 D_1^1$ = the zone 1 transformation matrix (refer to Fig. 8)

D^{23} = the zones 2 and 3 transformation matrix.

the product of which is the crusher transformation matrix, D^c.

$$D^c = D^{23} D^1 \qquad \text{Eq 31}$$

This is the methodology which has been incorporated in the SPOC module. To assist the interested user in understanding the source code documentation, Figure 10 is a logic flowchart for the construction of D^c. It is sufficiently general to solve problems caused by the user inputting incorrect information.

The only *wrinkle* in the source code arises when $m > 1$, that is, when there are two or more size intervals which are fully contained in zone 1. To avoid time consuming and wasteful matrix multiplication (see calculation of D^c above), a *pseudo matrix multiplication* algorithm was derived by the authors. In this case the column elements corresponding to the m stages are placed in the same matrix and when the entries are complete the pseudo matrix multiplication algorithm converts the matrix to the zone 1 transformation matrix, D^1.

Once the elements of D^c, d_{ij}, are known, the transformation computations are straightforward. Recalling the data structure defined earlier, the solids component mass balances are written as,

Primary Element

$$P_{ij1} = d_{ii} f_{ij1} + \sum_{m=1}^{i-1} d_{im} f_{mj1} \quad ; j=1,\ldots,NG \quad i=1,\ldots,NS \qquad \text{Eq 32}$$

where:

p_{ij1} = the primary element frequency for the crusher product.

d_{im} = an element of the crusher transformation matrix, D^c.

f_{ij1} = the primary element frequency for the crusher feed.

NG,NS = spec. grav. and size dimensionality.

Characteristic

$$P_{ijk} = \frac{d_{ii} f_{ij1} f_{ijk} + \sum_{m=1}^{i-1} d_{im} f_{mj1} f_{mjk}}{P_{ij1}} \quad k=2,\ldots,NC \quad j=1,\ldots,NG \quad I=1,\ldots,NS \qquad \text{Eq 33}$$

where:

p_{ijk} = the characteristic assay in the crusher product.

f_{ijk} = the characteristic assay in the crusher feed.

NC = total number of characteristics plus the primary element.

Since the crusher is a Single Input/Single Output (SISO) system, the water balance is trivial.

2.2.2.2 Constraints

The incomplete development of the model precludes the incorporation of explicit constraints. The user is directed to refer to published and/or vendor literature on

Flowchart for module VACRSH computation of zone I and zone 2/3 transformation matrices

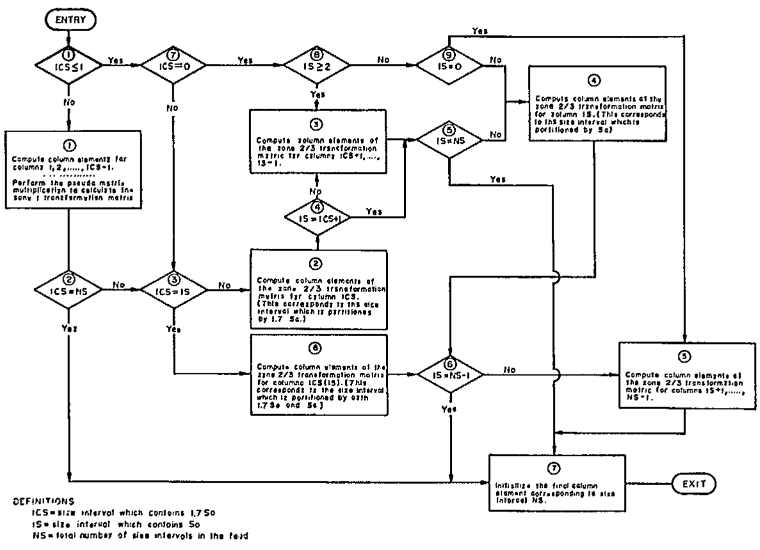


Fig. 10 — Flow chart for computation of transformation matrices for zone 1 and for zones 2 and 3 in the module VACRSH

the crushing unit being simulated, with a view to assessing the simulation results.

2.2.2.3 Limitations

Clearly, the biggest limitation of the model is its inability to account for liberation.

Other limitations include the inability to account for changes in comminution behaviour as a result of changes in operating conditions or the feed stream properties. Further, the use of lumped breakage and selection functions can introduce error, particularly if the gravity distribution changes considerably.

The compromise in using this model is accuracy versus simplicity. Since Valliant didn't publish any of the experimental data against which the model was presumably tested, its accuracy is purely speculative. However, with regard to the role which crushers currently play in coal preparation plant simulation, this seems quite a logical choice for a SPOC module, primarily on the basis of its simplicity.

2.2.3 Karra's Screen Model (KSCRN)

This model is based upon the work of Karra (3). The model uses the basic methodology employed by screen manufacturers to size screens. This model incorporates all the parameters which designers have deemed significant in evaluating a screen's performance. The model relationships were established from data obtained from 20 dry-screening tests carried out on a 1.5 × 1.7-m test plant vibrating screen with feedrate varied from 100-300 t/h and the aperture size from 5 to 50 mm. As far as can be determined, the model fits the observed data well.

The model basically relates the d50c empirically to the major equipment and feed stream parameters. A partition curve is used to describe the solid-solid separation relative to the d50c. The model is for either dry or wet screening (1-2% water added through sprays).

The Karra model has been modified for use in the SPOC simulator. These modifications are:

1. A fines bypass correction factor has been included as proposed by Mular (18).
2. A water split factor has been included by specifying, or assuming, an overflow moisture content.
3. As the bulk density of the ore may not be known, the bulk density is assumed to be 60% of the true density of the material.
4. Allowance for ore dependent variables will be made by permitting the user to include a correction factor to the d50c relationship, and the sharpness of separation factor (m) may also be specified if test information indicates that the actual value differs from the value specified by Karra, i.e., m = 5.85.

2.2.3.1 Mathematical derivation

The throughfall aperture of a square mesh screen is given by the equation:

$$h_T = (h + w) \cos \theta - w \qquad \text{Eq 34}$$

The terms of the above equation are defined in Figure 11. For rectangular openings the basic concept outlined by Equation 34 does not apply; h should be the minimum dimension and the w and θ should be specified as zero, such that Equation 34 becomes $h_T = h$.

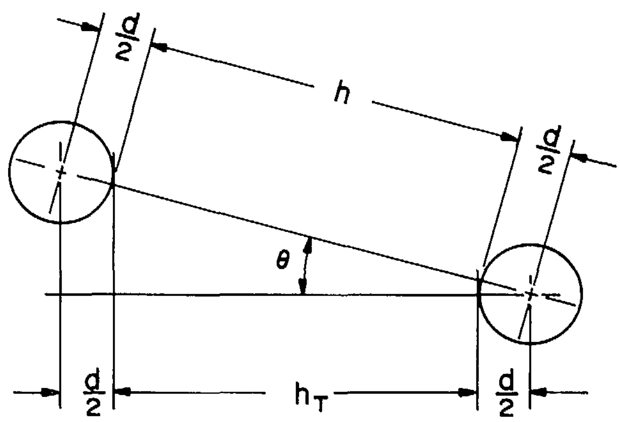


Fig. 11 — Throughfall aperture of an inclined screen

The relationship of d50 size to h_T is expressed as follows:

$$d50c = h_T \left(\frac{Tu/S}{KABCDEFG}\right)^{-0.148} \qquad \text{Eq 35}$$

where:

d50c	=	size at which particle has equal probability of reporting to fine and coarse products (in micrometres)
h_T	=	throughfall aperture size in micrometres
Tu	=	theoretical undersize tonnage (i.e., tonnes/h of material which would pass screen at 100% screening efficiency)
S	=	area of screen surface (square metres)
A	=	nominal screen capacity per unit area of screen
K	=	capacity calibration factor

B	=	oversize correction factor
C	=	halfsize correction factor
D	=	deck location factor
E	=	wet screening factor
F	=	density factor
G	=	nearsize factor.

The values for A, K, B, C, D, E, F, and G are given as follows:

A (for crushed stone)

$A = 1.3652\, h_T^{0.3162} - 10.2991 \qquad h_T < 50.800$

$A = 0.0003388\, h_T + 14.4122 \qquad h_T \geq 50.800$

K Calibration factor

K = 1.0 for crushed stone or *normal ore* and will vary with particle shape and type of ore (to be specified by the user based upon calibration data).

B Oversize factor

$B = -1.2\, Q + 1.6 \qquad Q \leq 0.87$

$B = -4.25Q + 4.275 \qquad Q > 0.87$

where:

Q = cumulative weight fraction of feed material less than h_T.

C Halfsize factor

$C = 1.2\, R + 0.7 \qquad R \leq 0.3$

$C = 2.0517\, R^{0.564} \qquad 0.3 < R \leq 0.55$

$C = 549.54\, R^{1.37} \qquad 0.55 < R \leq 0.8$

$C = 5\, R - 1.5 \qquad R > 0.8$

where:

R = cumulative fraction of feed material less than 0.5 h_T.

D Deck factor

$D = 1.1 - 0.1\, S$

where:

S = deck location in multiple deck screens, i.e., top S = 1, second screen S = 2, etc.

E Wet screening factor

$E = E_1\, h_T + E_2$

Value of h_T µm	E1	E2
< 800	0	1.0
800 – 1 600	0.00126	0
1 600 – 3 200	0.000315	1.5
3 200 – 4 800	0	2.5
4 800 – 7 900	−0.000126	3.25
7 900 – 9 500	−0.000315	4.5
9 500 – 13 000	−0.000063	2.1
13 000 – 19 000	−0.0001575	1.5
19 000 – 25 000	0.00000788	1.35
> 25 000	0	1.15

F Density factor

$F = \gamma/2.67$

where:

γ = mean specific gravity of feed solids.

G Nearsize factor

$G = 0.844\,(1 - X_n)^{3.453}$

where:

Xn = fraction of material in the feed greater than 0.75 h_T and less than 1.25 h_T.

The partition function used by the module is of the form:

$$y_i = (1 - \exp(-0.6931(\bar{d}_i/d_{50c})^m))\,(1 - R_f) + R_f$$

where:

$\bar{d}_i$ = the arithmetic mean diameter of size interval i.

R_f = fines bypass factor to account for carryover of fine particles sticking to coarse particles (user specified).

y_i = fraction of material in feed size interval i which is routed to the coarse product.

m = sharpness of separation coefficient (default 5.846).

The method employed to compute the oversize, half-size, and nearsize values is linear interpolation invoking the uniformity assumption (Appendix A).

To account for a water split around the screen it is assumed that the oversize will contain a user-specified maximum moisture content. If the feed contains less than the specified oversize moisture content, the water split will be the same as the solids split.

2.2.3.2 Constraints

To account for the inadequacies of Equation 35, d50c is constrained to be less than or equal to the aperture size h_T. This constraint is only encountered under very low screen loading.

For dry screening, the water content of the screen oversize is constrained to be equal to, or less than, the water content of the feed.

2.2.3.3 Limitations

The model is based on either dry or wet screening. For moist, sticky feed material, it would be expected that the screening action would deteriorate, and no provision is made for this in the model. Variations in speed and throw of the vibrating screen are also not accounted for in the model. In addition, the d50c equation is based upon crushed stone, and will change if the particle shape is much different.

It has been observed by Mular (18) and Batterham (22) that the sharpness of separation varies with feed rate. As the feed rate increases, the sharpness of separation decreases along with the d50c. The Karra model only decreases the d50c under these conditions. As the sharpness of separation is relatively high in any event, this inadequacy will usually not alter the predicted size distributions very significantly.

2.2.4 Whiten's Screen Model (WSCRN)

This mathematical model of the unit operation of screening was developed by Whiten (4) and further developed by Walter and Whiten (5). It appears to have been used, thus far, exclusively in the simulation of coarse screening operations, e.g., in mineral crushing circuits. From an historical point of view, this was the first screen model to be published in connection with modern mineral process simulation. Because of its successful application, its flexibility, and its mechanistic basis, it has been included as a SPOC module. However, it has been coded as an alternative to coarse screening in coal preparation applications (see Valliant's model below) and, as a result, a somewhat different stream data structure is used.

The theoretical model of vibrating screen developed by Whiten, is based on probability considerations, and is parameterized by least squares fitting against experimental data.

In essence, the model computes the mean probability that particles within a narrow size interval will report to the screen oversize product. Particles larger than the screen aperture will all report to the oversize stream. Particles smaller than the aperture have their probability computed as a function of particle size, aperture size, screen wire size, screen efficiency, screen load, and screen length. In regard to particles smaller than the aperture, the probability is computed via the classical definition of a mean, invoking the uniformity assumption. Characteristics, other than the weight frequency, are invariant since no size transformation is assumed to occur in the screening operation. Empirical means are provided for both completing water balances around the unit as well as accounting for the fine particles which *stick* to the coarser material, and report to the coarse product.

2.2.4.1 Mathematical derivation

Whiten's development begins by considering that the probability of passage of a particle of size, d, through a square mesh screen with aperture, h, and wire size, w, is given by Equation 36.

$$p'(d) = [(h-d)/(h+w)]^2 \;;\; d \le h \qquad \text{Eq 36}$$

where:

$p'(d)$ = probability that a particle with size $d \le h$ will pass through a square aperture of dimension h.

As Gaudin (23) has indicated "this ratio does not accurately reflect the probability of passage; it is a lower limit." Clearly, the expression does not account for those particles which bounce on the wire but still pass through the aperture. A schematic interpretation of Equation 36 is given in Figure 12.

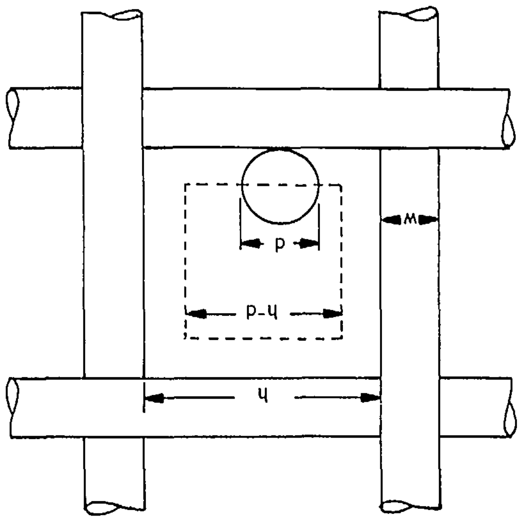


Fig. 12 — A schematic interpretation of the variables in Equation 36

The probability that the particle will not pass through the screen is then,

$$p(d) = 1 - p'(d) \;;\; d \le h \qquad \text{Eq 37}$$

where:

$p(d)$ = probability that a particle with size $d \le h$ will <u>not</u> pass through a square aperture of dimension h.

If the particle undergoes m independent trials in traversing the screen, the probability that it will report to the oversize product is given by Equation 38,

$$p(d) = \begin{cases} 1.0 & h \le d \\ \left[1 - \left[\dfrac{h-d}{h+w}\right]^2\right]^m & d < h \end{cases} \qquad \text{Eq 38}$$

where:

m ≅ number of *trials* a particle undergoes in traversing the screen.

The number of trials is assumed to be the same for all particles and is calculable from Equation 39.

$$m = k_1^2 \ell f \qquad \text{Eq 39}$$

where:

k_1^2 = an efficiency constant
ℓ = screen length
f = load factor.

Experimentally, the load factor and the efficiency constant can be incorporated into a single load-dependent parameter. Whiten defined the load factor to be,

$$f = \left[\frac{1}{1 + \left[\frac{k_2 V_f}{wh}\right]^2}\right] \qquad \text{Eq 40}$$

where:

k_2 = the loading constant
V_F = volumetric feed rate to the screen
w = screen width.

However, in his initial test work, the numerical value was observed to be approximately unity in all cases. (The load factor is expected to vary from 1 — at light screen loading to 0 — at very heavy screen loading. This factor can be thought of as a normalized particle residence time on the screen deck.) Setting f = 1, Lynch (6) has shown that k_1 varies with the solids flow rate to the screen.

To apply the model to a discretized size distribution of feed solids it is assumed that the solids are uniformly distributed, with respect to mass, within the interval. Thus, the mean probability for particles in the interval (d1, d2) is computed as,

$$\bar{p}_{(d_1,d_2)} = \frac{\int_{d_2}^{d_1} \left[1 - \left[\frac{h-d}{h+w}\right]^2\right]^m dd}{d_1 - d_2} \; ; \; d_1 \leq h \qquad \text{Eq 41}$$

where:

$\bar{p}(d_1,d_2)$ = the mean probability that particles contained in the interval (d_1,d_2) will not pass into the undersize product in m trials.
dd = integration increment of d (differential of d).

Expanding the probability expression in the integral via the binomial series, assuming m is large and the ratio of Equation 36 is small, allows the following approximation to be written:

$$\left[1 - \left[\frac{h-d}{h+w}\right]^2\right]^m = e^{-m\left[\frac{h-d}{h+w}\right]^2}$$

Substitution of this expression into Equation 41 and making use of a change in variable, namely,

$$y^2 = m\left[\frac{h-d}{h+w}\right]^2 \qquad \text{Eq 42}$$

$$y = \sqrt{m}\left[\frac{h-d}{h+w}\right] \qquad \text{Eq 43}$$

$$\bar{p}_{(d_1,d_2)} = \frac{\frac{-(h+w)}{\sqrt{m}} \int_{y_2}^{y_1} e^{-y^2}\,dy}{d_1 - d_2} \qquad \text{Eq 44}$$

The integral may be evaluated using the approximations.

$$\int_y^\infty e^{-y^2}\,dy = \left[\frac{0.12473}{[y^3 - 0.437885\,y^2 + 0.26682\,y + 0.138375]}\right]$$

and,

$$\int_0^\infty e^{-y^2}\,dy = 0.89$$

Since,

$$\int_{y_2}^{y_1} e^{-y^2}\,dy = \int_{y_2}^{\infty} e^{-y^2}\,dy - \int_{y_1}^{\infty} e^{-y^2}\,dy$$

Equation 44 can be rewritten as

$$\bar{p}_{(d_1,d_2)} = \frac{\frac{h+w}{\sqrt{m}} \left[\int_{y_1}^{\infty} e^{-y^2}\,dy - \int_{y_2}^{\infty} e^{-y^2}\,dy\right]}{d_1 - d_2} \qquad \text{Eq 45}$$

which is the form incorporated in the simulation module.

When the aperture, h, is contained within an interval, e.g., $d_i > h > d_i + 1$, the distribution of material in the partitioned intervals is calculated by linear interpolation,

$$f_a = \left[\frac{d_i - h}{d_i - d_{i+1}}\right] \qquad \text{Eq 46}$$

$$f_b = \left[\frac{h - d_{i+1}}{d_i - d_{i+1}}\right] \qquad \text{Eq 47}$$

where:

f_a = weight fraction in the interval (d_i,h)

f_b = weight fraction in the interval (h,d_{i+1}) and $f_a + f_b = 1.0$.

The material corresponding to f_a is assigned the probability

$$\bar{P}_{d_i,h} = 1.0$$

and that which corresponds to f_b has its probability computed via Equation 45.

To account for fine particles sticking to the coarse material and hence reporting to the coarse product, Whiten found a constant probability for the pan fraction was adequate. This value was typically about 0.1 but varied as high as 0.3 for wet sticky ores.

Thus far, the general model development has been restricted to size alone, which both simplifies symbolism as well as minimizes complexity for the uninitiated reader. However, it is necessary to apply the model to a data structure which is not unidimensional (size) but tridimensional (size by spec. grav. by characteristic). Given F and FS, the screen module must predict O, OS and U, US, given the throughfall aperture, the screen wire diameter, the screen efficiency constant, the screen length, and the load factor. The computations are simplified since size transformation is assumed to be absent in the screening operation. The solids component mass balances are written as,

Primary Element

$$o_{ij1} = \frac{\bar{p}(d_i,d_{i+1})FSf_{ij1}}{OS} \; ; \; j = 1, 2,..., NG \quad i = 1, 2,..., NS \qquad \text{Eq 48}$$

$$u_{ij1} = \frac{\left(1 - \bar{p}\,(d_i,d_{i+1})\right)FSf_{ij1}}{US} \; ; \; j = 1, 2,..., NG \quad i = 1, 2,..., NS \qquad \text{Eq 49}$$

where:

f_{ij1} = primary element frequency in the screen feed

o_{ij1} = primary element frequency in the screen oversize product

u_{ij1} = primary element frequency in the screen undersize product

OS = mass flow of solids in the screen oversize

US = mass flow of solids in the screen undersize

NG = number of specific gravity intervals in the solids arrays

NS = number of size intervals in the solids arrays

FS = mass flow of solids in the screen feed

and,

$$OS = \sum_i \sum_j \bar{p}(d_1,d_{i+1})FSf_{ij1}/100 \qquad \text{Eq 50}$$

$$US = FS - OS \qquad \text{Eq 51}$$

Characteristic

$$o_{ijk} = u_{ijk} = f_{ijk} \; ; \quad k = 2, 3,..., NC \quad j = 1, 2,..., NG \quad i = 1, 2,..., NS \qquad \text{Eq 52}$$

where:

o_{ijk}, u_{ijk}, f_{ijk} = characteristic assays on the solids stream (wt %)

NC = the number of characteristics plus one.

The Whiten model has been modified to allow for the computation of a water balance around the screen. This computation allows the user to specify the moisture content of the oversize stream. If this parameter exceeds the theoretical limit, it is constrained to divert all feed water to the overflow by default. Further, the absence of water in the feed stream causes this calculation to be ignored.

2.2.4.2 Constraints

The incomplete development of the model precludes the incorporation of explicit constraints. The user should refer to published and/or vendor literature on the screening unit being simulated, with a view to assessing the simulation results.

2.2.4.3 Limitations

Whiten's model was not developed, or tested, on materials of widely varying solids density, for example, coal. It is the opinion of the authors, however, that it can be reasonably applied to the coarse screening operations in coal preparation (see limitations for Valliant's model).

The principal disadvantages of the model, from a mechanical point of view, arise from the initial probabilistic assumptions and the lumped parameter treatment of the influence of operating conditions and feed stream properties.

2.2.5 Valliant's Screen Model (VSCRN)

This mathematical model of the unit operation of screening was developed by Valliant (1) for Gottfried's original Coal Preparation Plant Simulator. It was later included in the *enhanced* version of Gottfried's work developed by the Battelle Laboratories (2). Despite criticism of the model by Gottfried himself (24) and the relative abundance of alternative models in the mineral processing literature, little work, if any, has been done to improve modelling technology in coal preparation applications.

The screen model developed by Valliant can be shown to bear some resemblance to that which was formulated by Whiten. The model is relatively simple in form and requires a minimum of user input. However, the potential user must be aware of the computational risks which accompany the use of this model (see Limitations). For those users who lack a calibrated model of their coarse screening operations, this model will probably serve as a useful *default.*

Valliant indicates that the model is capable of simulating both wet and dry screening operations for both top and bottom deck screen locations for projected throughfall apertures in the interval (18 in., 0.01 in.). (It is the opinion of the authors that, while it may provide reasonable results for coarse screening simulations, the model validity is dubious, at best, in the finer size range, e.g., circa 28 mesh.)

In essence, the model computes the mean probability that particles contained within a narrow size interval will report to the oversize product. Particles having a size larger than the projected throughfall aperture will all report to the oversize stream. Particles with a size smaller than the projected throughfall aperture have their respective probabilities computed as a function of screen type/location, aperture, and particle size. To improve predictive performance, especially with *efficient (near perfect)* separation, the probability for the size interval of interest is computed via the classical definition of a mean, invoking the uniformity assumption. Characteristics, other than the weight frequency, are invariant since no particle size transformation is assumed to occur in the screening operation. An empirical means of accounting for water split around the screen is included to provide for approximate water balances in a simulation run.

2.2.5.1 Mathematical derivation

The mathematical model of the screening unit operation, as derived by Valliant, is given in Equation 53.

$$p(d) = \begin{cases} 1 & h \leq d \\ e^{-A(1-d/h)} & d < h \end{cases} \qquad \text{Eq 53}$$

where:

p(d) = probability that a particle of size, d, will report to the oversize stream
d = particle size
h = projected throughfall aperture
A = separation strength of the screen.

Neither the logic mechanism nor the mathematics of Valliant's development were satisfying to the author. In an effort to set the model on a *base* which would allow comparison with other mechanistic models found in the mineral-processing literature, an alternative derivation has been proposed.

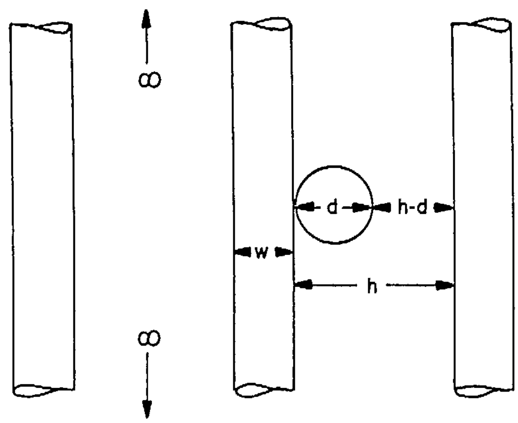


Fig. 13 — A schematic interpretation of the screen relative to the derivation of Valliant's model

The basic assumption is that one dimension of the aperture is much larger than the other. This allows one to think of a *basic unit screening distance (h + w)*, in a manner similar to Whiten's *basic unit screening area.* Carrying the analogy with Whiten's development one step further, one can suppose that the probability that a particle of size d will pass through the projected screen aperture, h, is the ratio of the excess distance, h − d, to the basic unit screening distance, i.e.,

$$p'(d) = \left[\frac{h-d}{h+w}\right] \; ; \; d \leq h \qquad \text{Eq 54}$$

where:

p′(d) = the probability that a particle of size d ≤ h will pass through a projected aperture of dimension h.

Thus, the probability that this particle will not pass through the screen is given by Equation 55.

$$p(d) = 1 - p'(d) \; ; \; d \leq h \qquad \text{Eq 55}$$

where:

p(d) = the probability that a particle of size d ≤ h will not pass through a projected aperture of dimension h.

If the particle undergoes m independent trials in traversing the screen, the probability that it will ultimately report to the oversize product is given by,

$$p(d) = \begin{cases} 1.0 & h \leq d \\ \left[1 - \left[\frac{h-d}{h+w}\right]\right]^m & d < h \end{cases} \qquad \text{Eq 56}$$

where:

m = number of independent trials a particle will undergo in traversing the screen.

Expanding the binomial expression and assuming that m is large and the probability of passage small allows the following approximation to be written,

$$p(d) = e^{-m}\left[\frac{h-d}{h+w}\right] \qquad \text{Eq 57}$$

which, in turn, can be written as,

$$p(d) = e^{-\left[\frac{mh}{h+w}\right](1-d/h)} \qquad \text{Eq 58}$$

where the term mh/(h+w) is taken as Valliant's separation strength, A.

A further point of refinement involving Equation 53 is that it is both possible and preferable to compute the mean probability for a particular size interval, rather than estimate it on the basis of a *characteristic size*. This is particularly true for steep partition curves, e.g., A>6. Assuming uniformity, the mean probability for the size interval (d_i,d_{i+1}) is written as

$$\bar{p}_{(d_i,d_{i+1})} = \frac{\int_{d_{i+1}}^{d_i} e^{-A[1-d/h]}\,dd}{[d_i - d_{i+1}]} \; ; d \leq h \qquad \text{Eq 59}$$

where:

$\bar{p}(d_i,d_{i+1})$ = mean probability that particles in the interval (d_i,d_{i+1}) will report to the oversize product

which, on solution, yields,

$$\bar{p}(d_i,d_{i+1}) = \begin{cases} 1 & h \leq d_{i+1} \\ \dfrac{h\left[e^{-A[1-d_i/h]} - e^{-A[1-d_{i+1}/h]}\right]}{A\,[d_i - d_{i+1}]} & ; d_i < h \end{cases} \qquad \text{Eq 60}$$

Equation 60, as the preferred form, is encoded in the screening module. (Note that this can create some slight differences in comparison to predictions made using Equation 53, particularly for *steep* partition curves.)

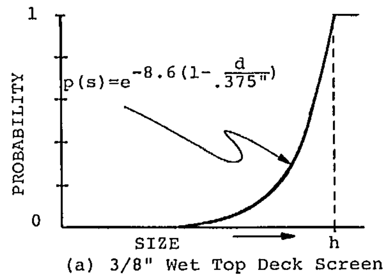
Valliant's screen model is potentially very robust for it uses tabulated values of the separation strength, A, as a function of projected throughfall aperture, deck location (top/bottom), and operating mode (dry/wet). These data are reproduced in Table 4.

For projected throughfall apertures, intermediate to those tabulated, linear interpolation is used to establish the screen separation strength. To illustrate the typical partition curves which result from the model, Figure 14 shows the results for a wet 3/8-inch screen and a wet 28-mesh screen, which are characteristic of coal preparation applications.

Thus far, the general model development has been restricted to size alone, which both simplifies symbolism as well as minimizes complexity for the uninitiated reader. However, it is necessary to apply the model to a data structure which is not unidimensional (size) but tridimensional (size by spec. grav. by characteristic). Given F and FS, the screen module must predict O, OS and U, US, given the throughfall aperture, the angle of screen inclination, and the mode of operation. The computations are simplified since size transformation is assumed to be absent in the screening operation. The solids component mass balances are written as,

Table 4 —The screen separation strength as a function of throughfall aperture, deck location, and the operation mode

Throughfall aperture (inches)	Dry upper deck	Dry lower deck	Wet upper deck	Wet lower deck
18.00	60.00	60.00	60.00	60.00
6.00	20.00	20.00	20.00	20.00
1.50	8.00	8.00	9.00	9.00
0.38	8.00	6.00	8.60	6.60
0.25	5.00	4.00	5.50	4.50
0.09	3.00	2.00	3.50	2.30
0.02	0.70	0.70	0.80	0.80
0.02	0.60	0.60	0.70	0.70
0.01	0.50	0.60	0.55	0.55



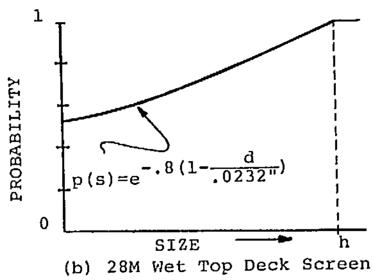


Fig. 14 – Typical partition curves for screens commonly encountered in coal preparation plants (VSCRN)

Primary Element

$$o_{ij1} = \frac{\bar{p}(d_i,d_{i+1})(FS)f_{ij1}}{OS} \; ; \; \begin{matrix} j = 1, 2,\dots, NG \\ i = 1, 2,\dots, NS \end{matrix} \qquad \text{Eq 61}$$

$$u_{ij1} = \frac{\left[1 - \bar{p}(d_i,d_{i+1})\right](FS)f_{ij1}}{US} \; ; \; \begin{matrix} j = 1, 2,\dots, NG \\ i = 1, 2,\dots, NS \end{matrix} \qquad \text{Eq 62}$$

where:

- FS = mass flow of solids in the screen feed
- f_{ij1} = primary element frequency in the screen feed
- o_{ij1} = primary element frequency in the screen oversize product
- u_{ij1} = primary element frequency in the screen undersize product
- OS = mass flow of solids in the screen oversize
- US = mass flow of solids in the screen undersize
- NG = number of specific gravity intervals in the solids arrays
- NS = number of size intervals in the solids arrays

and,

$$OS = \sum_i \sum_j \bar{p}(d_i,d_{i+1}))FSf_{ij1}/100 \qquad \text{Eq 63}$$

$$US = FS - OS \qquad \text{Eq 64}$$

Characteristic

$$o_{ijk} = u_{ijk} = f_{ijk} \; ; \; \begin{matrix} k = 2, 3, \dots, NC \\ j = 1, 2, \dots, NG \\ i = 1, 2, \dots, NS \end{matrix} \qquad \text{Eq 65}$$

where:

- o_{ijk}, u_{ijk}, f_{ijk} = the characteristic assays on the solids streams
- NC = the total number or characteristics plus one (wt %).

The water split expression allows the user to specify the moisture content of the oversize product. If this parameter exceeds the theoretical limit it is constrained to divert all feed water to overflow, by default. Further, the absence of water in the feed stream causes this calculation to be ignored.

2.2.5.2 Constraints

The incomplete development of the model prevents the incorporation of explicit constraints. The user should refer to published and/or vendor literature on the screening unit being simulated, with a view to assessing the simulation results.

2.2.5.3 Limitations

The screen model developed by Valliant ignores the effect of particle specific gravity on separation, considering only particle size. This seems reasonable provided that sufficient screening time is allowed. However, in the presence of high screen solids loading (esp. without wash water), a heavy-medium effect might be expected to enhance light particle short circuiting to the coarse product. Sampling studies by CANMET-W.R.L.* have corroborated Valliant's postulation regarding particle specific gravity.

Probably, the principal disadvantage of this model is its inability to account for solids loading, a feature which most other screen models incorporate. However, if one looks closely at Lynch's (6) data for coarse screens, screening efficiency is largely unaffected by loading over a broad range of solids feed rates. (This observation, coupled with the fact that the model claims to be able to handle wet screening, is directly responsible for its inclusion in SPOC.) The model also fails to account for operating conditions (e.g., throw, frequency, etc.) as well as the characteristics of the feed stream (e.g., near

**Personal communications with Mr. M. Mikhail.*

size material, etc.), which typically appear in other screening models, albeit usually in a lumped parameter format.

The compromise in using this model is accuracy versus simplicity. Unfortunately, Valliant did not publish any of the results of his development work, where the model was presumably tested against experimental data. Thus, this aspect is somewhat speculative.

2.2.6 Sieve Bend Model (BEND)

The only comprehensive model for the sieve bend (wedge wire) screen is that outlined by Lynch (6). The model is based upon tests carried out on lead-zinc ore using a sieve bend with three different slot widths: 250, 500, and 1000 μm. No results were presented to assess the validity of the model. Although simple in structure, the model appears to give reasonable predictions over the range of experimentation (250 to 1000 μm slot widths).

The Lynch model consists of a series of empirical equations which relate the partition curve parameters in terms of the feed stream characteristics and equipment variables. The only feed stream variables considered are feed slurry per cent solids (by weight), and the mass flow rate of water. The only equipment variable considered is the slot width (width of opening between the wedge bars). A constant sharpness of separation parameter is assumed for all operating conditions.

2.2.6.1 Mathematical derivation

The relationship to predict the water to the undersize (fine) product is,

$$WUS = 0.98(SW)^{0.33}WF - 0.6FPS + 2SW \qquad \text{Eq 66}$$

where:

WUS = mass flow rate of water in the undersize stream (tonnes/h)
SW = slot width in millimetres
FPS = per cent solids by weight in feed stream.

The cut size (d50c) is calculated with the equation,

$$\log_{10}d50c = 1.1718 \log_{10}SW + 0.001372\ WUS + 0.0029\ FPS + 2.45 \qquad \text{Eq 67}$$

where:

d50c = corrected cut size (micrometres).

A constant sharpness of separation (m = 2.9) is used as recommended by Lynch.

2.2.6.2 Constraints

As the equations used to predict water to undersize (WUS) and d50c are linear, there are no inherent limiting boundary conditions. Therefore, the equations only have a specific range of applicability for slot widths of 250 to 1000 μm. For example, for slot widths of over 1000 μm, the water in the undersize can become greater than the water in the feed. To prevent physically impossible conditions like this from occurring, a water split constraint is incorporated in the BEND module. This constraint limits the per cent solids in the oversize (coarse) stream to an arbitrary 85% solids by weight. If this constraint is exceeded, Equation 66 is ignored and the water split is calculated by fixing the oversize to 85% solids. In a similar manner, the d50c is not permitted to fall outside the bounds 0.40 SW to 0.85 SW as observed by Fontein (25).

2.2.6.3 Limitations

The main limitation of the model is that the tests used to formulate the model used slot widths which ranged from 250 to 1000 μm. The validity of the model outside this range is open to question. It should be noted that most mineral processing and coal sieve bend operations fall within this range. The second factor as pointed out by Lynch, is that the sieve bend performance changes with time due to blinding and wear of the wedge bars. Some screens are equipped with rapping devices to prevent blinding. These rapped screens would perform in an unsteady manner between raps.

No provision is made for a capacity constraint in the model. The width of the screen is not a parameter in the model. One manufacturer (26) recommends the following capacity limitations for satisfactory performance:

Slot widths μm	Max. slurry flow m^3/h/m width	Max. solids capacity tonnes/h/m width
100	2.7	0.7
420	27.0	7.0
1400	37.0	9.0

2.2.7 Hydrocyclone Model (HCONE)

This model is based upon the hydrocyclone study described in reference 7. Like the Lynch (27) model which preceded it, the model employs a partition curve and utilizes empirical correlations to relate the partition curve parameters with the cyclone dimensions and feed conditions. The correlations are based upon a large database involving over 200 tests on both laboratory and industrial scale cyclones. In addition to the large database used in its formulation, the model was selected for the SPOC simulator because most of the model equations have the same format as theoretical equations. Having a similar form means that the equations are more robust for extrapolation outside the region of experimentation. In addition the model has been utilized by several other modelling groups

(28,29,30,31) and is thus becoming a standard in the industry. The model equations are such that a hydrocyclone can be reasonably simulated even when no actual experimental calibration data are available.

The model accounts for the influence of five of the major dimensional variables which are illustrated in Figure 15. The properties of the slurry feed stream such as flow rate, solids density, and solids content are also included in the model. The model consists of three basic equations which calculate the parameters for a partition curve function (d50c, Rf, and m) in terms of the dimensional and feed stream variables. Also included in the module is a pressure-drop correlation. Pressure drop would be required for coupling the cyclone module with a pump-sump module for providing a capacity constraint.

The model incorporates the ability to handle solids of varying densities according to the relationship developed by Lynch (27). This feature is particularly necessary for use with coal where there is usually a significant variation in solids density.

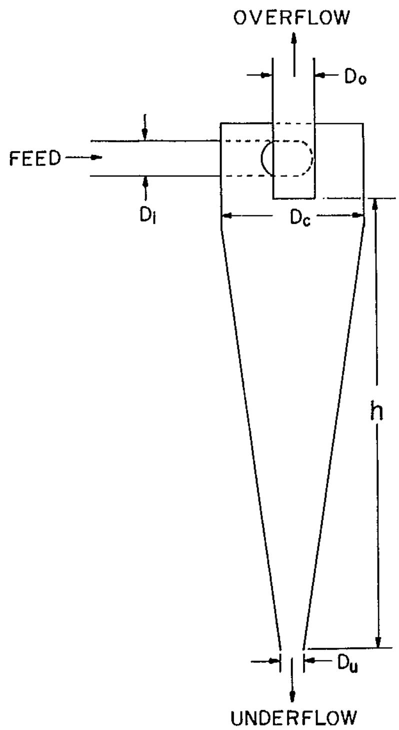


Fig. 15 — Principal dimensional variables of a hydrocyclone

2.2.7.1 Mathematical derivation

The model is based on a general equation for the reduced efficiency curve of hydrocyclones, i.e., the curve representing the corrected efficiency as a function of the d/d50c sizes (6,7).

$$y = 1 - \exp[-0.693(d/d50c)^{m}]$$

If m and d50c are calculated, the corrected efficiency curve cc = f(d)* is defined and a calculation of the water-split coefficient Rf completes the definition of the actual efficiency curve, c = f(d) which is related to cc by the correction equation

$$cc = \frac{c - Rf}{1 - Rf}$$

The model calculation is therefore performed in steps where the model variables d50c, m, and Rf are determined from empirical equations.

d50c correlation

The basic equation used in the SPOC hydrocyclone module to relate cut size to the operating and dimensional variables is:

$$d50c = \frac{39.7\ Fd50\ Dc^{0.46}\ Di^{0.6}\ Do^{1.21}\ \mu^{0.5}\ \exp(0.063\ \phi)}{Du^{0.71}\ h^{0.38}\ Q^{0.45}\ ((\rho s - \rho L)/1.6)^{K}} \qquad \text{Eq 68}$$

where:

- d50c = corrected d50 size (micrometres)
- Fd50 = calibration factor (when unknown set to 1.0)
- Dc = cyclone diameter (cm)
- Di = inlet diameter or equivalent (cm)
- Do = vortex finder (overflow) diameter (cm)
- ϕ = per cent solids by volume in feed slurry
- Du = apex (underflow) diameter (cm)
- h = free vortex height of cyclone (cm)
- Q = volumetric flow rate of feed slurry (litres/min)
- $\rho s, \rho L$ = specific gravity of solids, suspending fluid
- μ = fluid viscosity in centipoise.

The most important term which governs the d50c is the solids content of the feed slurry. Both Lynch and Plitt

*CC = f(d) means CC = function of d
C = f(d) means C = function of d*

have shown this to be represented by an exponential expression. The constant embodied in the equation (0.063) represents a lumped parameter which accounts for the influence of particle size distribution, particle shape, and surface chemistry on the apparent slurry viscosity. In a recent development of a cyclone model for a gold ore in South Africa (31), this constant was independently found to be 0.072. The dimensional parameters (Dc, Do, Du, Di, and h) of the hydrocyclone predict changes in the d50c in line with those observed in practice. The flow rate term is well established and appears in most d50c correlations. The relationship between d50c and net density can be derived from classical hydrodynamic theory:

$$d50c = \frac{C}{(\rho_s - \rho)^K}$$

where:

K = 0.5 for laminar settling conditions
K = 1.0 for turbulent settling conditions.

Several investigators (27,32,33) have verified this relationship with reported values of K ranging from 0.5 to 1.5. Those which exceed the theoretical bound (i.e., >1.0) are explained by the fact that the slurry density is greater than the fluid (i.e., water) density.

In the HCONE module, the suspending fluid is assumed to be water with a density of 1.0 and a viscosity of 1.0 centipoise. These parameters are initialized in the module and can easily be varied by adjusting the settings in the source code. Fd50 is included as a parameter in the module argument list to facilitate adjustment when the model is calibrated against test data. This parameter should only be adjusted when the d50c is measured with unrestricted flow from the apex. This means that d50c calibration tests should have an underflow solids content less than 40% solids by volume (see section on constraints).

Flow split correlation

The flow split (volumetric flow rate in underflow/volumetric flow rate in overflow) is calculated by the following equation:

$$S = \frac{FSPLT\ 1.9\ (Du/Do)^{3.31}\ h^{0.54}\ (Du^2 + Do^2)^{0.36}\ \exp(0.0054\phi)}{H^{0.24}\ Dc^{1.11}} \qquad \text{Eq 69}$$

where:

H = pressure drop expressed in head of feed slurry (metres)
FSPLT = calibration factor (set to 1.0 when no calibration data are available).

The pressure drop is calculated according to the fundamental statics equation:

$$H = \frac{P}{9.8\rho_p}$$

where:

P = pressure drop across the hydrocyclone (kilopascals)
ρ_p = density of feed slurry (pulp).

The flow split is used to calculate the water recovery to the underflow, Rf, according to the equation:

$$Rf = \frac{\frac{S}{1 + S} - R_s\ \phi/100}{1 - \phi/100} \qquad \text{Eq 70}$$

where:

R_s = fraction of feed solids recovered to the coarse product (underflow).

Since the calculation of R_s depends upon Rf, an iterative calculation is used to solve Equation 70. In his model, Lynch (27) calculates Rf directly which is computationally more efficient. His equation does not include Do (vortex finder diameter) which has been shown to strongly influence the flow split through the Du/Do ratio term. Thus, for robustness sake, Equation 69 was employed in the module. Normally, only two iterations are required to calculate Rf to be within 0.0001 of its assumed value which is deemed an acceptable computational overhead.

A calibration factor (FSPLT) is included in the argument list. Since Equation 69 is valid only for free discharge from both underflow and overflow, the flowsplit can be significantly altered by backpressure due to piping resistance or by syphoning, particularly with large diameter cyclones.

Sharpness of separation

The Plitt model had an equation to predict m, the sharpness of separation coefficient:

$$m = FEM\ 1.94\ \exp\left(-1.58\frac{S}{1 + S}\right)\left(\frac{Dc^2 h}{Q}\right)^{0.15} \qquad \text{Eq 71}$$

where:

FEM = calibration factor.

The main factor influencing m is S, the flow split. As more volume is routed to the underflow (increasing S) the poorer the sharpness of separation. This effect has been verified in other independent studies (28,8). Equation 71 will normally predict values of m ranging from 2 to

3. When measured values fall much below this range it usually signals the fact that there is a density distribution within the solids feed. Lynch (27) assumes that the sharpness of separation is solely an ore dependent variable and increases with increasing mineral density. The SPOC module permits the user to adopt either route, i.e., fix m to some predetermined constant value to allow it to be calculated according to Equation 71. A calibration parameter is provided to permit the user to calibrate Equation 71 to measured data.

Pressure drop correlation

Many pressure drop correlations exist for hydrocyclones. In the Plitt model, the pressure drop equation is:

$$P = \frac{FPRESS\ 1.88\ Q^{1.78}\ \exp(0.0055\phi)}{Dc^{0.37}\ Di^{0.94}\ h^{0.28}\ (Du^2 + Do^2)^{0.87}} \qquad \text{Eq 72}$$

where:

FPRESS = pressure drop calibration factor.

Equation 72 has the advantage over most.other pressure drop equations in that it includes the effect of apex diameter (Du) and the cyclone free vortex height (h). Most other equations neglect these terms.

The pressure drop may be significantly affected by the cyclone inlet configuration (volute entries offer lower resistance) which is not included in Equation 72. The position of the feed pressure gauge and the resistance of the overflow piping will contribute towards discrepancies between the observed pressure drop and that predicted by Equation 72.

2.2.7.2 Constraints

The major constraint built into the hydrocyclone module is that of the limiting solids concentration of the coarse product (underflow). When more solids are routed to the cyclone apex than its discharge capacity, the slurry exiting the apex loses its rotational motion and changes from spray to rope discharge. Very little quantitative information concerning this phenomenon is available in the literature. Mular and Jull (34) have presented a relationship between limiting per cent solids in the underflow and per cent solids in the overflow. The author has studied this problem on a 6-in. (15-cm) Krebs cyclone. The results of this study are summarized in Figure 16.

The facts which emerge from the various studies on rope discharge are:

1. The limiting per cent solids in the underflow stream ranges from 40 to 60% solids by volume. The main variable contributing to the limiting concentration is the size distribution of the solids (i.e., limiting concentration decreases as particle size of the feed decreases).

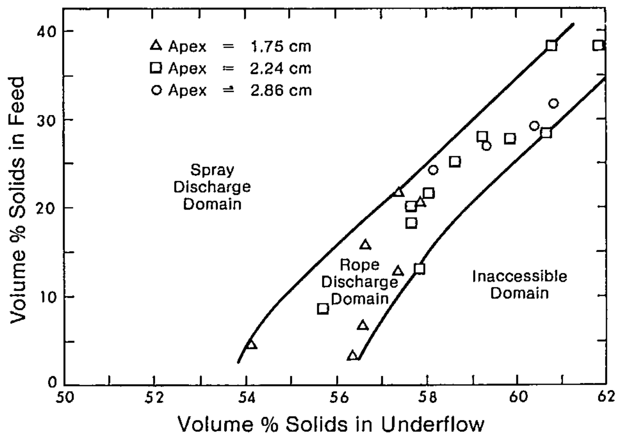


Fig. 16 — Rope discharge domain for a 15-cm diameter hydrocyclone

2. For a given feed size distribution, the limiting per cent solids in the apex increases as the feed solids concentration increases.
3. For feed solids with a mass median (50% passing) size greater than 200 mesh' the limiting underflow solids concentration is about 56% solids by volume at a feed of 20% solids by volume.
4. As the cyclone enters rope discharge, the sharpness of separation does not deteriorate as was commonly believed. There is evidence that the sharpness of separation may actually increase.
5. As the cyclone enters, or approaches, rope discharge, Equation 68 is invalidated. The d50c is determined solely on the basis of the solids-carrying capacity of the apex. The net result is that the d50c rises sharply as the cyclone enters rope discharge.

In the HCONE module, the apex constraint is handled as follows:

1. The nominal maximum fractional solids volume content in the underflow stream is specified by the user. The specified value is for a feed solids content of 20% solids by volume. The default value is 0.56 (ROPE).
2. The variation due to feed solids content is calculated by the equation:

$$Lu = Lu20 + 0.002\ (\phi - 20) \qquad \text{Eq 73}$$

where:

- Lu = limiting volumetric solids fraction in cyclone apex stream (underflow)
- Lu20 = limiting solids fraction in apex stream at 20% solids by volume in feed
- ϕ = per cent solids by volume in feed slurry.

3. If the constraint is encountered, the d50c is repetitively raised 5% until the underflow solids content falls below the limiting concentration Lu*. The number of iterations is stored in vector OUTPAR such that a message can be issued in the output routine that this constraint was encountered.

A second constraint is that of cyclone blocking. If the top size of the feed exceeds one third of the apex diameter, it is assumed that the apex will block. The module will route all the feed to the overflow and issue a message to this effect.

A third constraint is that of capacity. This can be handled by the calculated pressure drop. Any constraint in this regard will be controlled by the executive in coupling the pump/sump module with the hydrocyclone module.

2.2.7.3 Limitations

The HCONE module is very robust and has few inherent limitations. Some limitations are:

1. The apex constraint is limited to 60 iterations which correspond to a d50c increase of 18.7 times that originally calculated. This limitation will only be encountered if very coarse solids are fed to a small cyclone. An error message is printed if this limitation is encountered.
2. The calculation for underflow water is limited to five iterations. Normally only two are required. A message is printed if the convergence criterion is not met within five iterations.

2.2.8 Gravity Classification Model (GCLASS)

Gravity classifiers have been badly neglected in the modelling area. One of the best fundamental studies of gravity classification was carried out by Schubert and Nesse (8). In their study they defined the role of turbulence, eddy diffusion, and residence time upon the separation carried out in rake and spiral classifiers. Although their approach shows excellent promise in the formulation of a mechanistic mathematical model, parameter determination, particularly for eddy diffusion, is difficult to define in terms of realistic operating parameters. It was therefore decided to combine some of the concepts of Schubert and Nesse with the basic design procedures outlined by Roberts and Fitch (9) to formulate a hybrid model for the SPOC gravity classifier module.

The GCLASS module is primarily intended to simulate the action of mechanical classifiers (i.e., spirals and rakes). In a spiral classifier one or two large spiral conveyors are used in place of the oscillating rakes for coarse solids removal.

The model utilizes three equipment parameters: settling pool area, coarse solids removal capacity, and the solids content in the coarse solids stream. Using these three parameters and the characteristics of the feed stream the partition curve parameters (Rf, d50c, and m) are calculated. The solid–solid split is then determined. The d50c is calculated as being the particle which has a settling velocity equal to the mean upward rising velocity as illustrated in Figure 17. The sharpness of separation is calculated using the Schubert and Nesse tapping model for particle scattering converted to the Rosin-Rammler partition coefficient. As dilution water is normally added to the classifier, this parameter is specified separately and the dilution water is added to the water in the feed slurry. The model is fairly simple and straightforward and is applicable to any type of gravity classifier where the settling area can be defined, e.g., hydroseparators, classifier cones, etc.

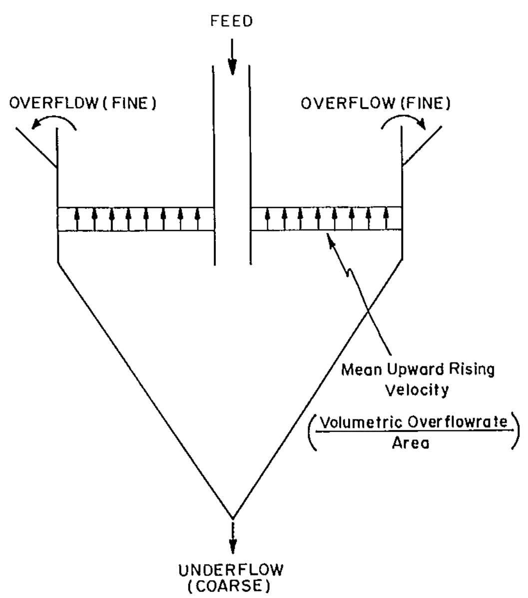


Fig. 17 — Schematic view of a simple classifier

**Computationally, this is a crude technique. However, since the limiting concentration is usually not known very precisely, a more sophisticated numerical technique seems unwarranted.*

2.2.8.1 Mathematical derivation

As mentioned earlier, the d50c size is assumed to be the size of particle which has a settling velocity equal to

$$v = \frac{Q_o}{A}$$

where:

Q_o = volumetric overflow rate
A = settling pool area.

The velocity is converted to particle size using the Swanson equation (35,36). Whereas Stokes' equation only applies for particles in the laminar settling regime, which limits its validity to about 70 μm (for quartz spheres in water), the Swanson equation does not have this limitation. The Swanson equation is valid under all settling regimes both laminar and turbulent. The Swanson equation is:

$$v = \frac{4/3\, g\, d^2 (\rho s - \rho)}{\alpha(2d^{3/2}\sqrt{\frac{g\rho s\rho}{3}} + \sqrt{48}\,\beta\mu)} \quad \text{Eq 74}$$

The values of α and β for various particle shapes are

	α	β	
Spheres	0.942	3.03	
Perfect cubes	1.038	3.01	e.g., galena, sylvite
Conchoidal fracture	1.022	4.008	e.g., quartz
Perfect dodecahedral	1.05	5.90	e.g., sphalerite
Plates: diam. = 10 × thickness	2.43	4.70	
diam. = 100 × thickness	7.69	12.29	e.g., mica
Irregular fracture	1.00	12.98	e.g., arsenopyrite.

The cubic values for α and β are internally set within the GCLASS module. These can be changed with a minor source code modification to any other desired shape.

Equation 74 is solved for d using successive iterations with convergence acceleration. This diameter is assumed to be the d50c of the classifier.

To apply hindered settling, the Concha and Almendra (37) equation is used to modify the apparent viscosity of the slurry,

$$\mu a = \mu o \frac{1 + 0.075^{1/3}}{(1 - 1.45\phi)^{1.83}} \quad \text{Eq 75}$$

where:

μa = apparent viscosity of slurry with fractional volumetric solids content of φ

μo = viscosity of slurry liquid (e.g., water).

The mean solids contents of the feed and overflow are used to determine the fluid density and viscosity in Equation 74.

To calculate the effective sharpness of separation parameter, the Schubert and Nesse relationship is utilized,

$$\frac{d75c}{d25c} = \sqrt{\frac{\ln(3/S)}{\ln(1/3S)}} \quad \text{Eq 76}$$

where:

S = volumetric flow rate split (coarse product volumetric flow rate/fine product volumetric flow rate)
dxxc = size with a corrected probability of xx% of reporting to coarse product.

Equation 76 is converted to the Rosin-Rammler sharpness of separation coefficient as follows,

$$m = \frac{\ln(\ln 4/\ln 1.33)}{\ln(d75c/d25c)} = \frac{1.57}{\ln\sqrt{\frac{\ln(3/S)}{\ln(1/3S)}}} \quad \text{Eq 77}$$

The user may specify a value for m. If no value is provided, the module will calculate m according to Equation 77.

The water split is calculated from the solids split applying a user-specified volume fraction of solids in the coarse product (sands). Roberts and Fitch (9) recommended the following values for solids content of the sands:

Cut size (d50c) μ	% Solids by vol. in sands
600	57 – 60
420	53 – 57
300	52 – 54
210	53
150	52
105	51
74	49
Hydroseparators	20 – 40

2.2.8.2 Constraints

The only constraint built into the GCLASS module is the solids raking capacity. This capacity is available from vendor literature for each classifier or from handbooks. If the coarse solids capacity exceeds the specified capacity, the d50c is iteratively increased in steps of 10% until the coarse solids mass flow rate falls below the capacity.

This simulates the action of coarse solids buildup in the machine, thus reducing the settling pool area and driving up the cut size.

2.2.8.3 Limitations

The main limitation to the GCLASS module is that it is unable to account for varying densities in the feed solids. If a varying feed density is presented, the average is used in all calculations. As there are no gravity classifiers in any coal preparation plants in Canada, it was deemed unnecessary to add the extra computational overhead involved in handling varying density minerals.

2.2.9 General Specific Gravity Separation Model (SGSEP)

The specific gravity separation model which has been chosen for implementation in SPOC is very simply the partition (i.e., distribution) curve which has been used in the industry for many years. There is no provision for predicting the effect on separation efficiency of changes in feed stream properties and/or the equipment-operating parameters. In general, this approach is satisfactory for predicting solids routing provided that unusual operating conditions are avoided.

"The distribution curve for clean coal (or refuse) is, in general, characteristic of the individual cleaning unit and independent of the density composition of the feed. It is considered to be dependent upon such factors as the nature and operation of the cleaning unit, the medium, the size composition of the feed, and the feedrate." (14) It has been observed in practice that density independence is a good assumption provided unusual operating circumstances are absent. The effects of size composition are handled by constructing partition curves for individual size fractions. While a limited amount of effort has been given to empirically predicting the influences of other factors, this has been largely isolated in design studies and integration with mathematical models, at least in the published literature, has yet to occur.

Using data which were published by the USBM for the following separation unit operations:

- dense medium vessel/bath (38)
- dense medium cyclone (39)
- jig (40)
- table (41)
- automedium cyclone (i.e., compound water cyclone, hydrocyclone) (42).

Gottfried (1), and later the Battelle Laboratories (2), constructed simulation modules which incorporated this partition curve information as a default database. The experimental testwork involved unit performance tests at several plants and the concept of density independence was strongly supported by the findings. Gottfried (43) observed that by plotting the generalized partition curves for a particular size fraction, in scatter diagram form, they were, to a good approximation, a single curve. Hand drawing a best-fit curve through these points and subsequently extracting this information in digitized form provided a general partition curve for a particular unit and size fraction. This then could be used with an interpolation routine (e.g., Lagrange Method) to predict the partition factor given a reduced particle specific gravity (particle s.g. divided by the s.g. of separation). Because of the apparent absence of this kind of information in the public domain and the rather extraordinary effort required to obtain it for a given plant, Gottfried's (Battelle's) data have been included in SPOC as an optional default database.

In the special case of the jig where very frequently a middlings stream is produced, Gottfried attempted to define two *simultaneous* general partition curves (clean coal and middlings). Mathematically, as well as intuitively, this is not a very satisfying methodology to the authors. Apparently* this is not standard practice; rather, a units-in-series approach is preferred. Thus, a three-product device of any type must be modelled as two *two-product* units in series for the purpose of SPOC.

Gottfried (43) and others (44,45) have also attempted to use continuous mathematical functions to characterize the partition curve. However, observation of typical partition curves, especially for hydraulic devices, where particle size effects cannot be totally suppressed, would indicate that interpolation is still the preferred method of solution.

The generalized partition curve contains the implicit assumption that any variation in the operation of the unit may be explained by changes in the specific gravity of separation. Quite simply, this means that, using some specified partition curve, the only decision variable for the module is the specific gravity of separation.

The SPOC module accepts as operating inputs the feed stream properties and the specific gravity of separation. The model itself is passed to the module in the form of several arrays which contain both the partition curves, in digitized form, as well as the size intervals to which they pertain.

There are two factors which serve to complicate the calculations. The first arises from the fact that the observed (back-calculated) specific gravity of separation may not be equal to the specified values. This occurrence requires an iterative solution of the model with the convergence criterion being defined as the difference between these two values. Convergence acceleration (Secant Method) and iteration stability monitoring ($\leq$10 cycles) are both included in the module.

**Personal communication with S.G. Butcher (March 1980).*

The second factor which complicates the calculations is the possibility that the sample (feedstream) and reference (partition curve) size intervals may not exactly coincide. In this case it is necessary to construct a *bridge* which describes the influence of a certain partition curve on a feed-size fraction, as a function on the overlap between the sample and the reference size intervals. Such a bridge is easy to construct by invoking the uniformity assumption.

The default database, provided in Tables 5 to 9 (2), show the reduced density as a function of the composite specific gravity of separation. Therefore, on any iteration, with the current value for the internal specific gravity of separation (which is different from either the observed or specified values), and the bridging function, a clean coal and refuse stream can be predicted. From this, a new observed specific gravity of separation is calculated and used for convergence control calculations.

Table 5 – Generalized curve data for dense-medium vessel from Vol. 1, Battelle documentation

Plus 4 inches		4 inches by 2 inches		2 inches by 1 inch		1 inch by ½ inch		Minus ½ inch	
c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean
.9399	1.000	.9104	1.000	.8719	1.000	.7828	1.000	.8434	1.000
.9457	.997	.9221	.989	.8737	.993	.9322	.993	.8629	.997
.9487	.993	.9320	.977	.9205	.978	.9474	.987	.8887	.991
.9496	.980	.9437	.959	.9394	.962	.9595	.976	.9207	.975
.9612	.700	.9506	.945	.9553	.940	.9666	.954	.9485	.956
.9690	.500	.9584	.919	.9682	.906	.9757	.860	.9712	.931
.9787	.260	.9653	.800	.9731	.844	.9908	.700	.9867	.899
.9903	.012	.9810	.500	.9811	.700	1.0100	.500	.9898	.880
.9923	.006	.9859	.400	.9930	.500	1.0353	.247	1.0104	.690
.9932	.003	.9957	.210	1.0059	.288	1.0555	.046	1.0310	.500
.9961	.000	1.0045	.040	1.0208	.068	1.0656	.025	1.0527	.300
1.0010	.000	1.0075	.027	1.0258	.048	1.0807	.013	1.0640	.208
1.0078	.000	1.0153	.013	1.0357	.030	1.0938	.007	1.0722	.160
1.0175	.000	1.0242	.005	1.0476	.015	1.1161	.001	1.0826	.120
1.0271	.000	1.0359	.000	1.0575	.009	1.1272	.000	1.1083	.071
1.0368	.000	1.0369	.000	1.0774	.000	1.1282	.000	1.1393	.040
1.0465	.000	1.0379	.000	1.0784	.000	1.1292	.000	1.1702	.020
1.0562	.000	1.0389	.000	1.0794	.000	1.1302	.000	1.2114	.006
1.0659	.000	1.0399	.000	1.0804	.000	1.1312	.000	1.2372	.002
1.0756	.000	1.0408	.000	1.0814	.000	1.1322	.000	1.2753	.000

Table 6 — Generalized curve data for dense-medium cyclone from Vol. 1, Battelle documentation

Plus ½ inch		½ inch by ⅜ inch		⅜ inch by ¼ inch		¼ inch by 8 mesh		8 mesh by 14 mesh		Minus 14 mesh	
c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean
.9413	1.000	.9069	1.000	.8939	1.000	.8761	1.000	.8458	1.000	.8076	1.000
.9502	.997	.9148	.997	.9315	.992	.8891	.999	.8763	.997	.8336	.996
.9602	.990	.9297	.991	.9415	.987	.8991	.998	.8967	.994	.8701	.988
.9652	.983	.9396	.985	.9474	.982	.9141	.996	.9181	.986	.8857	.983
.9681	.978	.9475	.978	.9543	.973	.9441	.988	.9426	.969	.9378	.958
.9691	.970	.9644	.970	.9563	.968	.9590	.979	.9599	.951	.9639	.937
.9950	.500	.9574	.952	.9712	.760	.9670	.965	.9731	.928	.9795	.917
1.0179	.066	.9742	.940	.9910	.500	.9790	.800	.9782	.914	.9899	.897
1.0199	.054	.9890	.500	1.0059	.280	.9990	.500	.9823	.896	.9951	.880
1.0229	.040	1.0088	.220	1.0217	.056	1.0140	.320	.9986	.720	1.0160	.710
1.0278	.030	1.0216	.040	1.0237	.044	1.0300	.120	1.0190	.500	1.0420	.500
1.0358	.020	1.0236	.029	1.0277	.034	1.0390	.088	1.0496	.194	1.0785	.206
1.0448	.012	1.0286	.019	1.0386	.020	1.0539	.062	1.0567	.156	1.0889	.130
1.0547	.006	1.0385	.008	1.0524	.010	1.0739	.046	1.0771	.100	1.0941	.110
1.0647	.002	1.0513	.002	1.0653	.005	1.0989	.024	1.0954	.073	1.1045	.089
1.0726	.000	1.0632	.000	1.0812	.000	1.1289	.010	1.1229	.050	1.1358	.055
1.0736	.000	1.0642	.000	1.0822	.000	1.1389	.006	1.1617	.029	1.1723	.036
1.0746	.000	1.0652	.000	1.0832	.000	1.1578	.000	1.1973	.016	1.3546	.014
1.0756	.000	1.0661	.000	1.0842	.000	1.1588	.000	1.2452	.006	1.5703	.000
1.0766	.000	1.0671	.000	1.0851	.000	1.1598	.000	1.3247	.000	1.5713	.000

Table 7 — Generalized curve data for single-stage Baum jig from Vol. 1, Battelle documentation

Plus 3 inches		3 inches by 1⅝ inches		1⅝ inches by ½ inch		½ inch by ¼ inch		¼ inch by 8 mesh		8 mesh by 14 mesh		Minus 14 mesh	
c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean
.8432	1.000	.8463	1.000	.8056	1.000	.7999	1.000	.7093	1.000	.7653	1.000	.7656	1.000
.8488	.997	.8529	.998	.8328	.997	.8248	.997	.7467	.995	.7891	.996	.7968	.998
.8526	.987	.8606	.990	.8570	.991	.8486	.989	.7904	.985	.8086	.990	.8385	.990
.8601	.979	.9015	.907	.8882	.977	.8767	.971	.8258	.970	.8302	.980	.8880	.975
.8836	.880	.9120	.869	.8993	.967	.9016	.945	.8528	.952	.8453	.969	.9374	.948
.9137	.699	.9225	.814	.9053	.955	.9156	.922	.8798	.931	.8691	.937	.9635	.925
.9400	.500	.9292	.750	.9637	.699	1.0097	.681	.8986	.899	.9275	.840	1.0156	.873
.9739	.223	.9530	.500	1.0070	.500	1.0810	.500	.9568	.733	.9751	.739	1.1497	.702
.9908	.080	.9730	.300	1.0523	.299	1.1761	.275	1.0400	.500	1.0810	.500	1.3020	.500
.9936	.064	.9787	.250	1.0916	.131	1.1880	.255	1.1055	.366	1.1264	.397	1.3619	.422
.9983	.047	.9892	.201	1.0976	.113	1.2096	.229	1.1710	.255	1.1448	.369	1.3853	.400
1.0058	.032	.9987	.169	1.1087	.093	1.2453	.197	1.1960	.217	1.1718	.337	1.4244	.376
1.0152	.019	1.0159	.129	1.1248	.075	1.2864	.169	1.2158	.194	1.2129	.397	1.4921	.343
1.0293	.006	1.0340	.097	1.1409	.065	1.3318	.145	1.2501	.168	1.2734	.250	1.6171	.298
1.0340	.003	1.0454	.083	1.1651	.057	1.4118	.115	1.2958	.142	1.4745	.119	1.7421	.267
1.0406	.000	1.0559	.075	1.2739	.034	1.5329	.086	1.3624	.144	1.5372	.089	1.9400	.229
1.0415	.000	1.1131	.035	1.4551	.015	1.6788	.061	1.4414	.088	1.6129	.064	2.1848	.193
1.0425	.000	1.1741	.000	1.7522	.000	1.8377	.040	1.5558	.062	1.7318	.038	2.6040	.143
1.0440	.000	1.1750	.000	1.7532	.000	1.8388	.040	1.7763	.028	1.8982	.018	2.6043	.143
1.0449	.000	1.1760	.000	1.7542	.000	1.8399	.040	2.0800	.000	2.0539	.010	2.6066	.143

Table 8 — Generalized curve data for concentrating table from Vol. 1, Battelle documentation

Plus ½ inch		¼ inch by 8 mesh		8 mesh by 14 mesh		14 mesh by 28 mesh		28 mesh by 48 mesh		48 mesh by 100 mesh		Minus 100 mesh	
c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean
.8181	1.000	.8290	1.000	.7646	1.000	.7362	1.000	.7515	1.000	.7479	1.000	.7345	1.000
.8694	.993	.8509	.997	.8279	.997	.7954	.993	.7813	.994	.8122	.977	.7757	.998
.8793	.987	.8648	.993	.8425	.994	.8051	.991	.8018	.987	.8798	.941	.8242	.992
.8802	.978	.8747	.987	.8620	.981	.8245	.983	.8306	.968	.9250	.908	.8775	.981
.9030	.960	.8847	.977	.8766	.960	.8391	.972	.8635	.932	.9723	.862	.9211	.969
.9129	.940	.8966	.963	.8961	.920	.8488	.962	.8861	.900	1.0017	.823	.9696	.947
.9218	.920	.9045	.948	.9058	.880	.8633	.939	.9252	.800	1.0332	.758	1.0132	.919
.9267	.900	.9314	.900	.9497	.635	.8827	.887	1.0280	.500	1.1280	.500	1.0326	.900
.9416	.800	.9433	.800	.9740	.500	.9021	.817	1.1514	.200	1.1573	.420	1.0908	.800
.9586	.690	.9642	.675	1.0227	.279	.9700	.500	1.1925	.135	1.1731	.375	1.2120	.500
.9880	.500	.9940	.500	1.0519	.148	1.0379	.246	1.2336	.099	1.2171	.300	1.2847	.400
1.0186	.300	1.0288	.300	1.0665	.100	1.0573	.195	1.2953	.066	1.2634	.237	1.3623	.339
1.0532	.080	1.0387	.240	1.0909	.068	1.0864	.145	1.3364	.052	1.3762	.100	1.4544	.292
1.0581	.060	1.0626	.180	1.1201	.046	1.1252	.103	1.3981	.040	1.3987	.080	1.5998	.243
1.0670	.043	1.0835	.099	1.1688	.025	1.1689	.073	1.6448	.026	1.4326	.060	1.6968	.219
1.0769	.033	1.1093	.060	1.2272	.018	1.2853	.040	1.8504	.021	1.4890	.040	1.9392	.177
1.0868	.026	1.1332	.040	1.6558	.000	1.4308	.015	2.0560	.020	1.5566	.030	2.4240	.120
1.0977	.023	1.1610	.026	1.7532	.000	1.6189	.000	2.1074	.020	2.2560	.020	2.4846	.120
1.2844	.011	1.1928	.018	1.8506	.000	1.7460	.000	2.1588	.020	2.3124	.020	2.5452	.120
1.4820	.000	1.5467	.000	1.9480	.000	1.9400	.000	2.2102	.020	2.3688	.020	2.6058	.120

Table 9 — Generalized curve data for hydrocyclone from Vol. 1, Battelle documentation

Minus 4 mesh		4 mesh by 8 mesh		8 mesh by 14 mesh		14 mesh by 28 mesh		28 mesh by 65 mesh		65 mesh by 100 mesh		Minus 100 mesh	
c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean	c-Reduced specific gravity	Ratio to clean
.5670	1.000	.5052	1.000	.3875	1.000	.2868	1.000	.3491	1.000	.5635	1.000	.6810	1.000
.5994	.991	.5894	.962	.4520	.981	.3633	.989	.4565	.995	.6127	.999	.8513	.985
.6383	.965	.6652	.908	.4951	.965	.4589	.968	.5553	.983	.6738	.994	1.1577	.890
.6699	.930	.7241	.835	.5467	.939	.5507	.941	.6659	.954	.8441	.954	1.1781	.876
.6958	.890	.7578	.768	.5984	.905	.5908	.925	.8055	.886	.9508	.910	1.1918	.863
.7128	.857	.7999	.646	.7103	.971	.6682	.881	.8485	.858	.9844	.891	1.2054	.844
.7371	.793	.8420	.500	.7964	.678	.7648	.806	.9022	.814	.0096	.873	1.3620	.500
.7476	.758	.8715	.400	.8352	.595	.8528	.713	.9419	.769	1.0479	.838	1.3892	.440
.7630	.702	.9052	.298	.8610	.500	.8986	.640	.9612	.735	1.0791	.793	1.4097	.400
.8100	.500	.9262	.247	.9041	.332	.9560	.500	1.0740	.500	1.1990	.500	1.4369	.361
.8262	.440	.9649	.175	.9213	.277	1.0267	.326	1.3210	.094	1.2482	.381	1.4710	.321
.8570	.339	1.0045	.115	.9514	.221	1.0516	.279	1.3339	.078	1.2913	.313	1.4982	.295
.9185	.153	1.0390	.070	1.0117	.140	1.1013	.200	1.3694	.049	1.3549	.246	1.5731	.230
.9437	.109	1.0794	.048	1.0616	.095	1.1453	.140	1.4016	.033	1.5143	.212	1.6072	.205
.9769	.074	1.1687	.029	1.1064	.067	1.2237	.063	1.4306	.024	1.5587	.093	1.6276	.193
1.0368	.034	1.3135	.012	1.1451	.053	1.2638	.041	1.4499	.020	1.6103	.069	1.6548	.179
1.1057	.017	1.3977	.004	1.2269	.035	1.3002	.030	1.5057	.017	1.6546	.053	1.7025	.157
1.1988	.007	1.5139	.000	1.3561	.017	1.7151	.011	1.6916	.012	1.8117	.021	1.7910	.123
1.2798	.003	1.5148	.000	1.5068	.003	2.2179	.000	2.0606	.000	1.9184	.009	1.8728	.100
1.3770	.000	1.5156	.000	1.6359	.000	2.2275	.000	2.0513	.000	2.0383	.000	1.8741	.100

2.2.9.1 Mathematical derivation

In mathematical terms, the module is very simple. Given a particular value for the internal specific gravity of separation, ρ^c (which would be equal to the specific value on the first iteration), it is possible to compute a mass distribution factor to the clean coal product as:

$$c_{kj} = f\,(S_k,\ S_{k+1},\ \bar{\rho}_j,\ \rho^c) \qquad \text{Eq 78}$$

where:

- c_{kj} = the mass fraction of the j^{th} specific gravity interval of the k^{th} reference size interval which reports to the clean coal product.
- $f(\ )$ = shorthand symbolism representing interpolation.
- S_k, S_{k+1} = size bounds on the k^{th} reference size interval (denoting a specific partition curve).
- $\bar{\rho}_j$ = mean specific gravity of the j^{th} interval which is computed from the bounds ρ_j and ρ_{j+1} as,

$$\bar{\rho}_j = \frac{[\rho_j + \rho_{j+1}]}{2} \qquad \text{Eq 79}$$

- ρ^c = internal size composite specific gravity of separation.

Assuming uniformity, the bridging function elements may be calculated in direct proportion to the overlap between the sample and reference size intervals as:

$$b_{ik} = \begin{cases} 0 & ;\ d_{i+1} > S_k \text{ or } S_{k+1} \geq d_i \\ 1 & ;\ S_k \geq d_i > d_{i+1} \geq S_{k+1} \\ \left[\dfrac{d_i - S_{k+1}}{d_i - d_{i+1}}\right] & ;\ S_k \geq d_i \geq S_{k+1} \geq d_{i+1} \\ \left[\dfrac{S_k - d_{i+1}}{d_i - d_{i+1}}\right] & ;\ d_i \geq S_k \geq d_{i+1} \geq S_{k+1} \\ \left[\dfrac{S_k - S_{k+1}}{d_i - d_{i+1}}\right] & ;\ d_i \geq S_k \geq S_{k+1} \geq d_{i+1} \end{cases} \qquad \text{Eq 80}$$

where:

- b_{ik} = overlap of the k^{th} reference size interval on the i^{th} sample size interval (the bridging element).
- d_i, d_{i+1} = the size bounds on the i^{th} sample size interval.

and,

$$\sum_k b_{ik} = 1.0$$

The component mass balances are then calculated as:

Primary Element

$$\hat{p}_{ij1} = \sum_{k=1}^{m} b_{ik} c_{kj} \hat{f}_{ij1} \ ;\ j = 1,2,\ldots,NG \quad i = 1,2,\ldots,NS \qquad \text{Eq 81}$$

where:

- $\hat{p}_{ij1}$, $\hat{f}_{ij1}$ = mass flow of material in the i^{th} size by j^{th}, e.g., interval in the clean coal and feed, respectively.
- m = number of reference size intervals.
- NG = number of specific gravity intervals in the solids arrays.
- NS = number of size intervals in the solids arrays.

The refuse product is computed by difference as:

$$\hat{r}_{ij1} = \hat{f}_{ij1} - \hat{p}_{ij1} \qquad \text{Eq 82}$$

and finally, the frequency distribution is obtained by solving

$$p_{ij1} = \frac{100\ \hat{p}_{ij1}}{\sum_i \sum_j \hat{p}_{ij1}} \ ;\ j = 1,2,\ldots,NG \quad i = 1,2,\ldots,NS \qquad \text{Eq 83}$$

$$r_{ij1} = \frac{100\ \hat{r}_{ij1}}{\sum_i \sum_j \hat{r}_{ij1}} \ ;\ j = 1,2,\ldots,NG \quad i = 1,2,\ldots,NS \qquad \text{Eq 84}$$

where:

- p_{ij1}, r_{ij1} = primary element frequency for clean coal and refuse products, respectively.

With respect to the characteristic values the computations are trivial, since size transformation is assumed to be absent in this class of unit operations.

Characteristics

$$p_{ijk} = r_{ijk} = f_{ijk} \qquad k = 2,3,\ldots,NC \quad j = 1,2,\ldots,NG \quad i = 1,2,\ldots,NS \qquad \text{Eq 85}$$

where:

- p_{ijk}, r_{ij1}, f_{ijk} = the characteristic assay.
- NC = the total number of characteristics plus the primary element.

Having performed these calculations for the current value of ρ^c, the size composite distribution factors for the specific gravity intervals may be evaluated as,

$$v_j = \sum_i \hat{p}_{ij1} \Big/ \sum_i \hat{f}_{ij1} \qquad \text{Eq 86}$$

where:

v_j = size composite mass distribution fraction to the clean coal product.

Using inverse interpolation, the observed specific gravity of separation, ρ^o, may be estimated. Now, with the specified value, ρ^s, the convergence criterion, c, is calculated as,

$$c = |\rho^s - \rho^o| \qquad \text{Eq 87}$$

If this meets the tolerance requirement (0.0003) then the specified value is set equal to the observed value and the rest of the computations above are performed.

If this does not meet the tolerance requirement, then the new value of ρ^c is calculated and the process repeated, to a maximum of 10 iterations. The new estimate of ρ^c is computed from,

$$\rho^c_{\ell+1} = \begin{cases} \rho^c_\ell + [\rho^s - \rho^o_\ell] & ; \ell = 1 \\ \rho^c_\ell - [\rho^s - \rho^o_\ell] \left[\dfrac{\rho^c_\ell - \rho^c_{\ell-1}}{\rho^o_{\ell-1} - \rho^o_\ell}\right] & ; 2 \leq \ell \end{cases} \qquad \text{Eq 88}$$

where:

ℓ = the iteration number, N.B. for $\ell \geq 2$ convergence acceleration is employed.

Unlike size analyses, the lower limit on the specific gravity distribution is nonzero, and typically would have a value of circa 1.25. This value has been *hard-wired* into the SPOC modules (SGSEP, SGSOUT, SGDOUT) and shouldn't require modification unless washability data conditions dictate the contrary. In this case the user must alter the value (SGLOW) in the module code.

The model is equipped to perform a simple water split where the user specifies the percentage moisture content in the clean coal stream. This value is constrained to lie within the theoretical limits if it is found to be incompatible with the unit performance.

2.2.9.2 Constraints

The incomplete development of the model precludes the incorporation of explicit constraints. The user is directed to refer to published and/or vendor literature on the various types of specific gravity separation unit being simulated, with a view to assessing the simulation results.

2.2.9.3 Limitations

The limitations of the model were discussed above. The principal limitations are the lack of explicit relationships between the partition curve shape and the equipment operating and feed stream properties (viz. HCONE Module).

Despite this limitation, a rather significant amount of relevant digital simulation work can be done using this first approximation model. This is evidenced by the fact that all engineering and many exploration companies utilize similar models in everyday process evaluation runs.

2.3 PROGRAM CAPABILITIES

Each unit simulator is a subroutine called by a standard argument list. This list has been chosen to be as close as possible to that used in the MODSIM simulator (46):

(NS,NG,NC,SOL1,WAT1,CH1,SOL2,WAT2,CH2,SOL3, WAT3,CH3,SOL4,WAT4,CH4,DER1,DER2, DER3,PARAM,OPT)

where:

- NS = Number of size fractions.
- NG = Number of specific gravity intervals.
- NC = Number of characteristics. A characteristic is any physical assay by which the solid is characterized: weight, % Cu, % ash, BTU, etc. By convention, the first characteristic must be the solid weight.
- SOLi = Flow rate of solid in stream i (i = 1 to 4).
- WATi = Flow rate of water in stream i (i = 1 to 4).
- CHi = Three-dimensional array of dimensions NS, NG, NC containing the solid characteristics for stream i (i = 1 to 4).
- DERi = Numerical derivative of characteristic CH(i+1) (i = 1 to 3). Three-dimensional arrays provided to store the numerical derivative of characteristic i + 1 with respect to its value in the feed (CH1). This option is unused but could be activated to study linearization of complex models.
- PARAM = A vector of model parameters specific to each model.
- OPT = A vector of options relative to each model.

The size vector XMU and the specific gravity vector SG are passed by labelled COMMON/SZSG with a fixed dimension of 20 and 10, respectively.

Each module also includes a pool of memory transmitted by COMMON/POOL for local memory requirements of up to 1000 words. This pool is distributed to local variables by an EQUIVALENCE statement.

2.4 DATA INPUT

Each simulator reads a set of data in file No. 5 through subroutine RDFILE. Subsequently, subroutine UDRIVR prints the data divided into six tables and the user is prompted to accept or modify interactively each of the six groups:

1. NS,NG,NC,SOL1,WAT1.
2. Three-dimensional feed characteristics entered as NC sets of NS records of NG values.
3. Vector PARAM.
4. Vector OPT.
5. Vector XMU.
6. Vector SG.

2.4.1 ROTARY

```
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 (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 SETS
           OF NS RECORDS EACH RECORD HAVING NG VALUES)
          (% WEIGHT)

PARAM   = PARAMETER VECTOR - 1 = LENGTH
                             2 = DIAM
                             3 = HOLE
LENGTH  = BREAKER LENGTH IN METRES
DIAM    = BREAKER DIAMETER IN METRES
HOLE    = BREAKER DRUM APERTURE SIZE IN MICROMETRES

OPT     = OPTION VECTOR        1 = FLAG
FLAG    = FLAG TO REQUEST DETAILED OUTPUT ON PRODUCT STREAMS
        = 0 :  SUMMARY OUTPUT
        = 1 :  SUMMARY PLUS DETAILED OUTPUT

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

2.4.2 VACRSH

```
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 (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 SETS
           OF NS RECORDS EACH RECORD HAVING NG VALUES)
          (% WEIGHT)

PARAM   = PARAMETER VECTORS - 1 = SET
                              2 = CONST
SET     = CRUSHER SETTING (MICROMETRES)
CONST   = CRUSHER CONSTANT

OPT     = OPTION VECTOR      -  1 = MODE
                                2 = TYPE
                                3 = FLAG
MODE    = 1 FOR PRIMARY CRUSHER
          2 FOR SECONDARY CRUSHER
TYPE    = 1 FOR A CAGE MILL CRUSHER
          2 FOR A SINGLE ROLL CRUSHER
          3 FOR A MULTIPLE ROLL CRUSHER
          4 FOR A GYRATORY/JAW CRUSHER
FLAG    = FLAG TO REQUEST DETAILED OUTPUT ON PRODUCT STREAMS
          0 SUMMARY OUTPUT
          1 SUMMARY PLUS DETAILED OUTPUT

XMU     = VECTOR OF UPPER SIZES FOR THE INTERVALS (MICROMETRES)
SG      = VECTOR OF UPPER BOUNDS OF SPECIFIC GRAVITY INTERVALS
```

2.4.3 KSCRN

```
NS      = NUMBER OF SIZE FRACTIONS (PAN INCLUDED)
NG      = NUMBER OF SPECIFIC GRAVITY FRACTIONS
NC      = NUMBER OF CHARACTERISTICS
SOL     = SRFD = MASS FLOW RATE OF SOLIDS IN FEED (TONNES/HR)
WAT     = WRFD = 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 SETS
           OF NS RECORDS EACH RECORD HAVING NG VALUES)
          (% WEIGHT)

PARAM    = PARAMETER VECTOR  -  1 = BYPASS
                                2 = CAP
                                3 = WATOF
                                4 = EM
                                5 = APER
                                6 = ANGLE
                                7 = WIRE
                                8 = DECK
                                9 = AREA
                               10 = WET
BYPASS   = FRACTION OF FINES BYPASSED TO COARSE DUE TO STICKING
CAP      = CAPACITY CORRECTION FACTOR TO ADJUST D50 CORRELATION
WATOF    = PERCENT MOISTURE IN OVERSIZE STREAM
EM       = SHARPNESS OF SEPARATION FACTOR (DEFAULT = 5.846)
APER     = MINIMUM SCREEN OPENING (MICROMETRES)
ANGLE    = ANGLE OF SCREEN TO THE HORIZONTAL (DEGREES)
WIRE     = WIRE DIAMETER (MICROMETRES), SET TO 0.0 FOR SLOTTED OR
           NON-SQUARE SCREENS
DECK     = POSITION OF SCREEN IN MULTIPLE DECK SCREEN
           (TOP = 1:  SECOND = 2: ETC.)
AREA     = AREA OF SCREEN SURFACE (SQ. METRES)
WET      = TONNES/HR OF WATER ADDED THROUGH SPRAYS
           (TYPICAL VALUES = 0.015 TO .025 * SOL)

OPT      = OPTION VECTOR      - 1 = FLAG
FLAG     = FLAG TO REQUEST DETAILED OUTPUT ON PRODUCT STREAMS
         = 0:  SUMMARY OUTPUT
         = 1:  SUMMARY PLUS DETAILED OUTPUT

XMU      = PASSING SIZE FROM COARSE TO FINE (MICROMETRES)
SG       = VECTOR OF UPPER SPECIFIC GRAVITIES FOR
           THE INTERVALS
```

2.4.4 WSCRN

```
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 (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 SETS
          OF NS RECORDS EACH RECORD HAVING NG VALUES)
         (% WEIGHT)

PARAM  = PARAMETER VECTOR - 1 = APER
                            2 = WIRE
                            3 = EFF
                            4 = DIST
                            5 = FACT
                            6 = BYPASS
                            7 = WATOF
APER   = SCREEN THROUGHFALL APERTURE (NOT CORRECTED FOR
         INCLINATION)
WIRE   = SCREEN WIRE DIAMETER (MICROMETRES)
EFF    = EFFICIENCY FACTOR
DIST   = SCREEN LENGTH IN METRES
FACT   = LOAD FACTOR
BYPASS = FRACTION OF SUBMESH MATERIAL WHICH REPORTS TO OVERSIZE
WATOF  = % MOISTURE IN OVERSIZE

OPT    = OPTION VECTOR    - 1 = FLAG
FLAG   = FLAG TO REQUEST DETAILED OUTPUT ON PRODUCT STREAMS
       = 0 :  SUMMARY OUTPUT
       = 1 :  SUMMARY PLUS DETAILED OUTPUT

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

2.4.5 VSCRN

```
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 (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 SETS
          OF NS RECORDS EACH RECORD HAVING NG VALUES)
         (% WEIGHT)

PARAM  = PARAMETER VECTOR - 1 = APER
                            2 = ANGLE
                            3 = WATOF
APER   = SCREEN THROUGHFALL APERTURE (NOT CORRECTED FOR
         INCLINATION)
ANGLE  = ANGLE OF INCLINATION OF SCREEN (DEG)
WATOF  = % MOISTURE IN OVERSIZE PRODUCT

OPT    = OPTION VECTOR      - 1 = FLAG
                              2 = MODE
                              3 = LOCAT
FLAG   = FLAG TO REQUEST DETAILED OUTPUT ON PRODUCT STREAM
MODE   = 1 FOR A DRY SCREEN
         2 FOR A WET SCREEN
LOCAT  = 1 FOR THE TOP DECK
         2 FOR THE BOTTOM DECK

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

2.4.6 BEND

```
NS    = NUMBER OF SIZE FRACTIONS
NG    = NUMBER OF SPECIFIC GRAVITIES
NC    = NUMBER OF CHARACTERISTICS
SOL   = SRFD = SOLIDS FLOW RATE IN FEED(TONNES/HR)
WAT   = WRFD = WATER FLOW RATE IN THE FEED(TONNES/HR)

FEED  = 3 DIMENSIONAL ARRAY CONTAINING THE CHARACTERISTICS
        OF THE FEED

PARAM = PARAMETER VECTOR - 1 = SW
                           2 = EM
SW    = SLOT WIDTH (MICROMETRES)
EM    = SHARPNESS OF SEPARATION COEFFICENT

OPT   = OPTION VECTOR (UNUSED)

XMU   = SIZE VECTOR (MICROMETRES)
```

2.4.7 HCONE

THREE DIFFERENT MODULES OF HCONE CAN BE USED:

HCONE1 - CALCULATES THE CYCLONE REDUCED EFFICIENCY CURVE FROM CYCLONE GEOMETRY AND OPERATING CONDITIONS

HCONE2 - CALCULATES THE CYCLONE CORRECTED EFFICIENCY FROM GIVEN PARAMETERS D50C, EM AND RF AS DESCRIBED IN SECTION 2.2.7.1

HCONE3 - READS DIRECTLY THE REAL EFFICIENCY CURVE

EACH OF THE THREE MODULES READS ITS OWN DATA FILE.

NS = NUMBER OF SIZE FRACTIONS (PAN INCLUDED)
NG = NUMBER OF SPECIFIC GRAVITY FRACTIONS
NC = NUMBER OF CHARACTERISTICS
SOL = SRFD = MASS FLOW RATE OF SOLIDS IN FEED (TONNES/HR)
WAT = WRFD = 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 SETS OF NS RECORDS EACH RECORD HAVING NG VALUES) (% WEIGHT)

FOR HCONE1

PARAM = PARAMETER VECTOR - 1 = CN
2 = DU
3 = ROPE
4 = DC
5 = DO
6 = DI
7 = FD50
8 = FSPLT
9 = FPRESS
10 = FEM
11 = FVH

CN = NUMBER OF CYCLONES IN PARALLEL
DU = INSIDE DIAMETER OF UNDERFLOW ORIFICE OR SPIGOT (TYPICAL RANGE 0.3*DO TO 0.8*DO) (CM)
ROPE = NOMINAL LIMITING FACTOR OF SOLIDS IN UNDERFLOW FOR A FEED OF 20% SOLIDS BY VOLUME
DC = INSIDE DIAMETER OF CYCLONE AT THE BOTTOM OF VORTEX FINDER (CM)
DO = INSIDE DIAMETER OF VORTEX FINDER OR OVERFLOW OUTLET (TYPICAL RANGE 0.15*DC TO 0.4*DC) (CM)
DI = INLET DIAMETERS (OR AREA EQUIVALENT) AT POINT WHERE INLET ENTERS THE MAIN BODY OF CYCLONE(CM)
FD50 = ORE DEPENDENT CORRECTION FACTOR FOR D50 CORRELATION (SET TO 1.0 WHEN NO CALIBRATION DATA ARE AVAILABLE)
FSPLT = UNDERFLOW/OVERFLOW VOLUME SPLIT FACTOR (SET TO 1.0 FOR NORMAL OPERATION)
FPRESS = PRESSURE DROP FACTOR (SET TO 1.0 FOR NORMAL OPERATION)

```
     FEM     = SHARPNESS OF SEPARATION CALIBRATION FACTOR
               (SET TO 1.0 FOR NORMAL OPERATION)
     FVH     = FREE VORTEX HEIGHT OR DISTANCE BETWEEN TOP
               OF APEX ORIFICE TO BOTTOM OF THE VORTEX
               FINDER (TYPICAL VALUES 2*DC TO 4*DC)

     OPT     = OPTION VECTOR      - 1 = 1 (FOR HCONE1)

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

FOR HCONE2:
----------

     PARAM   = PARAMETER VECTOR      - 1 = CN
                                       2 = DU
                                       3 = ROPE
                                       6 = RF
                                       7 = EM
                             8 TO (7+NG) = WORK5
     CN      = NUMBER OF CYCLONES IN PARALLEL
     DU      = INSIDE DIAMETER OF UNDERFLOW ORIFICE (CM)
     ROPE    = NOMINAL LIMITING FACTOR OF SOLIDS IN UNDERFLOW
               FOR A FEED OF 20% SOLIDS BY VOLUME
     RF      = WATER RECOVERY TO THE UNDERFLOW (FRACTION)
     EM      = SHARPNESS OF SEPARATION COEFFICENT
     WORK5   = VECTOR OF D50C = CORRECTED EQUI-PARTITION
               DIAMETERS

     OPT     = OPTION VECTOR        - 1 = 2 (FOR HCONE2)

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


FOR HCONE3:
----------

     PARAM   = PARAMETER VECTOR     - 1 = CN
                                      2 = DU
                                      3 = ROPE
                                      4 = PJ
                                      5 = RF
                            6 TO (5+NS) = EFFICENCY CURVE VECTOR
     CN      = NUMBER OF CYCLONES IN PARALLEL
     DU      = INSIDE DIAMETER OF UNDERFLOW ORIFICE (CM)
     ROPE    = NOMINAL LIMITING FACTOR OF SOLIDS IN UNDERFLOW
               FOR A FEED OF 20% SOLIDS BY VOLUME
     RF      = WATER RECOVERY TO THE UNDERFLOW (FRACTION)
     PJ      = % SOLIDS BY VOLUME IN UNDERFLOW

     OPT     = OPTION VECTOR         - 1 = 3 (FOR HCONE3)

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

2.4.8 GCLASS

```
NS      = NUMBER OF SIZE INTERVALS
NG      = NUMBER OF SPECIFIC GRAVITY FRACTIONS
NC      = NUMBER OF CHARACTERISTICS (WEIGHT, ASSAYS, ETC.)
SOL     = SRFD = SOLIDS MASS FLOWRATE IN THE FEED (TONNES/HR)
WAT     = WRFD = WATER MASS FLOWRATE IN THE FEED (TONNES/HR)
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)
         (% WEIGHT)

PARAM   = PARAMETER VECTOR - 1 = DILWAT
                             2 = AREA
                             3 = EM
                             4 = CSCAP
                             5 = PSVCS
DILWAT  = MASS FLOW RATE OF DILUTION WATER ADDED TO
          CLASSIFIER (TONNES/HR)
AREA    = EFFECTIVE OVERFLOW POOL AREA(SQUARE METER)
EM      = SHARPNESS OF SEPARATION COEFFICIENT
CSCAP   = COARSE SOLID REMOVAL CAPACITY (SOLIDS
          RAKING CAPACITY)
PSVCS   = PERCENT SOLIDS BY VOLUME IN COARSE PRODUCTS

OPT     = OPTION VECTOR (UNUSED)

XMU     = VECTOR OF PASSING SIZES FROM COARSE TO FINE
          (MICROMETRES)
SG      = VECTOR OF UPPER BOUNDS OF SPECIFIC GRAVITY
          INTERVALS
```

2.4.9 SGSEP

```
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 (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 SETS
           OF NS RECORDS EACH RECORD HAVING NG VALUES)
          (% WEIGHT)

PARAM   = PARAMETER VECTOR    - 1 = SGSP
                                2 = WATOF
SGSP    = SPECIFIC GRAVITY OF SEPARATION
WATOF   = PERCENT MOISTURE IN THE CLEAN COAL PRODUCT

OPT     = OPTION VECTOR       - 1 = FLAG
                                2 = TYPE
FLAG    = FLAG REQUESTING OUTPUT OF DETAILED EQUIPMENT
          AND STREAM CHARACTERISTICS
        = 0:  SUMMARY OUTPUT
        = 1:  SUMMARY PLUS DETAILED OUTPUT
TYPE    = SPECIFIES THE PARTICULAR SEPARATION DEVICE
        = 1:  DENSE MEDIUM VESSEL
        = 2:  DENSE MEDIUM CYCLONE
        = 3:  JIG
        = 4:  CONCENTRATING TABLE
        = 5:  AUTOMEDIUM CYCLONE

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

2.5 PRINTED OUTPUT

The flowchart for VACRSH is given in Figure 10. An extensive use of comments in the FORTRAN programs makes it relatively simple to follow the computation path for other unit simulators.

Output Modules and Auxiliary Routines

Each of the SPOC simulation modules has a summary output routine which provides an overview of the equipment performance. The format for these output routines generally includes a graphic schematic of the unit (e.g., ISO Flow sheet Symbol) showing the macrocomponent flow rates (water, solids, and possibly slurry) as well as the decision variables passed to the simulation module. This is followed by a table showing the distribution of solids as a function of either particle size or specific gravity, whichever is deemed more relevant to the nature of the equipment. In some cases (e.g., HCONE), calculated equipment parameters may be passed between the simulator and the summary output routine. The actual output from any of these subprograms is shown in the Sample Runs portion of the written documentation. Table 10 gives the names for the summary output subroutines.

In addition to the summary output subprograms, there are two special output routines. Subroutine DETOUT is a detailed output routine which is intended for use primarily with multidimensional solids streams. Those units capable of handling coal solids can flag DETOUT from the summary output subprograms. In this case a detailed description of the product stream(s) is presented. The output format shows the specific gravity distribution within each size fraction. Direct values, i.e., those computed on the basis of the entire solids stream, and cumulative values, i.e., those computed on a cumulative basis for a particular size interval, are characteristic.

Table 10 — Summary output routines

Unit operation	Summary-output subroutine
Rotary breaker	ROTOUT
Crusher	VACOUT
Coarse screen (Karra)	KAROUT
Coarse screen (Whiten)	WHSOUT
Coarse screen (Valliant)	VASOUT
Sieve bend	BENOUT
Hydrocyclone	CYCOUT
Gravity classifier	GCLOUT
Specific gravity separator	SGSOUT

The second special output routine, SGDOUT, is used exclusively in conjunction with the specific gravity separation module, SGSEP. Its function is simply to compute some of the more common measures of process separation efficiency for the unit operation under consideration. This subprogram, like DETOUT, is summoned from SGSOUT via the flag.

None of the output routines have been documented in this report since, for the most part, their function/operation is relatively simple. It could be argued that SGDOUT is sufficiently complex to warrant written documentation; however, special effort was made to provide sufficient in-line source code documentation.

The auxiliary routines consist of linear interpolation (LINEAR), Lagrangian interpolation (LAGRAN), the Rosin-Rammler partition curve calculations (PART), and the data input and modification routines, RDFILE and UDRIVR. Two other subroutines, PLOTSZ and INITGR, are used to provide a line plot of the size distributions of the feed and cyclone products. These subprograms have been documented in the system documentation section of this report.

3. SYSTEM DOCUMENTATION

3.1 COMPUTER EQUIPMENT

All programs have been tested on a CDC CYBER computer, operating under NOS/BE. Peripheral equipment can include card reader, time-sharing terminal, line printer, and disk drives.

3.2 SOURCE PROGRAMS

Enquiries about source programs should be directed to:

Technology Information Division
CANMET,
Energy, Mines and Resources Canada
555 Booth Street
Ottawa, Ontario
K1A 0G1.

3.3 MAIN PROGRAM AND SUBROUTINES

As described in Section 2.4, each unit simulator is driven by a short program allowing the entry of default data from a file, its optional modification, and the actual simulation. The general list of arguments described in Section 2.3 is used for all process units. The parameter list specific to each unit is given in Section 2.4 and repeated in the preamble of all sample runs in Section 5. Only the auxiliary routines DETOUT, SGDOUT, PLOTSZ, INITGR, and those listed at the end of Section 2.5 are now described.

3.3.1 Subroutine: DETOUT

3.3.1.1 Purpose

To output detailed information upon request from a summary data subroutine.

3.3.1.2 Usage

CALL DETOUT (NS, NG, NC, ARRAY).

3.3.1.3 Parameters list

NS = number of size fractions (pan material included)

NG = number of specific gravity fractions

NC = number of characteristics

ARRAY = three-dimensional array containing the solids characteristic *assays* for the stream.

3.3.1.4 Remarks

This subroutine is a collection of WRITE and FORMAT statements. Comments are omitted.

Stream titles must be generated in the calling program.

3.3.1.5 Subroutines and functions required

None.

3.3.2 Subroutine: SGDOUT

3.3.2.1 Purpose

To compute *some* of the more common measures of process unit efficiency for a particular specific gravity separation unit operation.

3.3.2.2 Usage

CALL SGDOUT (NS, NG, NC, FEEDS, FEED, COALS, COAL, TYPE).

3.3.2.3 Parameters list

NS = number of size fractions (pan material included)

NG = number of specific gravity fractions

NC = number of characteristics

FEEDS = mass flow rate of solids in the feed

FEED = three-dimensional array containing the solids characteristic *assays* for the separation unit feed stream

COALS = mass flow rate of solids in the clean coal product

COAL = three-dimensional array containing the solids characteristic *assays* for the clean coal product

TYPE = specifies the particular separation device

1 = dense-medium vessel
2 = dense-medium cyclone
3 = jig
4 = concentration table
5 = automedium cyclone.

3.3.2.4 Remarks

All units of flow measurement must be consistent.

3.3.2.5 Subroutine and functions required

LAGRAN.

3.3.3 Subroutine: PLOTSZ

3.3.3.1 Purpose

To plot size distributions in cumulative weight per cent as a function of the passing sieve size.

3.3.3.2 Usage

Call PLOTSZ (NS, N, IMASK).

3.3.3.3 Parameters list

NS = number of size fractions

N = number of plots

IMASK = vector of curve symbols: F = feed, P = product, O = overflow, U = underflow.

3.3.3.4 Subroutines and functions required

INITGR.

3.3.4 Subroutine: INITGR

3.3.4.1 Purpose

To initialize a plotting vector on a line printer by either blanks (IFLAG $\neq$ 1) or dashes to draw the X axis (IFLAG = 1).

3.3.4.2 Usage

Call INITGR (IFLAG).

3.3.4.3 Parameters list

IFLAG $\neq$ 1 to initialize a row of blanks
1 to initialize a row of dashes.

3.3.5 Subroutine: LINEAR

3.3.5.1 Purpose

To perform a univariate linear interpolation from a table of values of X vs Y.

3.3.5.2 Usage

CALL LINEAR (NPTS, XPTS, YPTS, XINT, YCAL, IERR).

3.3.5.3 Parameters list

NPTS = the number of X Y pairs

XPTS = vector containing the values of X

YPTS = vector containing the values of Y

XINT = the value of X where Y is to be calculated

YCAL = the calculated value of Y at XINT

IERR = a return variable to indicate if X is out of range.

3.3.5.4 Remarks

XPTS must be either increasing or monotone decreasing; if the independent variable (X) lies outside the range then the dependent variable (Y) is assigned the value of the appropriate end point.

3.3.5.5 Subroutines and functions required

None.

This module is one of the auxiliary subroutines used by some of the simulation modules (ROTARY, VACRSH, and VSCRN). Its purpose is to perform a univariate linear interpolation from a table of values of X vs Y.

The values of X must be either monotone decreasing or increasing. Once it has been determined whether the X values are increasing or decreasing, a test is made to determine where the X of interest lies in the table of X's. If the X of interest is equal to one of the values in the table, the corresponding Y value is returned. If the X of interest lies outside the limits of the table of X's, the value of Y corresponding to the appropriate end point is returned. If an end point is returned for the Y value, a return variable IERR is set to 1, indicating the X of interest is out of range. If the X of interest is within the range of X values and does not equal one of the table values, tests are made to determine the interval which bounds X ($X_i < X < X_{i+1}$). Linear interpolation is then used to determine the corresponding dependent variable Y.

3.3.6 Subroutine: LAGRAN

3.3.6.1 Purpose

To perform a univariate four-point, Lagrangian interpolation from a table of values of X vs Y.

3.3.6.2 Usage

CALL LAGRAN (NPTS, XPTS, YPTS, XINT, YCAL, IERR).

3.3.6.3 Parameters list

NPTS = the number of X Y pairs

XPTS = a vector containing the values of X

YPTS = a vector containing the values of Y

XINT = the value of X for which Y is to be calculated

YCAL = the calculated value of Y

IERR = a return variable to indicate if X is in range.

3.3.6.4 Remarks

The values of X must be monotone increasing or decreasing.

3.3.6.5 Subroutines and functions required

None.

This module is one of the auxiliary subroutines used by SGSEP and SGDOUT to perform a four-point Lagrangian interpolation from a table of values of X vs Y.

The values of X must be either monotone decreasing or increasing. Once it has been determined whether the X values are increasing or decreasing, a test is made to determine where the X of interest lies in the table of X's. If the X of interest is equal to one of the values in the table, the corresponding Y value is returned. If the X of interest lies outside the limits of the table of X's, the value of Y corresponding to the appropriate end point is returned. If an end point is returned for the Y value, a return variable IERR is set to 1, indicating the X of interest is out of range. If the X of interest is within the range of X values and does not equal one of the table values, tests are made to determine the interval which bounds X ($Xi < X < Xi+1$). If the X of interest is contained in one of the extreme intervals, linear interpolation is used to determine the value of the dependent variable. For an X of interest contained within the rest of the table, a four-point Lagrangian interpolation can be used.

After the dependent variable has been calculated via this method, a test is made on the monotonicity of the Y points and for conditions of extreme curvature. If the tabulated Y values are monotonic over the range of interest and the interpolated point is either greater or less than its nearest neighbours, this constitutes a condition of extreme curvature and the Y value corresponding to X is recalculated by linear interpolation.

3.3.7 Subroutine: PART

3.3.7.1 Purpose

To carry out a solid–solid separation using the Rosin-Rammler expression for a size-based partition curve including fines bypass.

3.3.7.2 Usage

CALL PART (MODE, NS, PARAM, FEED, D50C, EM, RF, RS, COARSE, FINE).

3.3.7.3 Parameters list

MODE = 1: for HCONE1, KSCRN, GCLASS, and BEND
= 2: for HCONE2
= 3: for HCONE3

NS = number of size intervals

PARAM = dummy variable for all except MODE = 3 where PARAM = fixed partition curve vector

FEED = weight per cent in each size fraction in FEED

D50C = corrected D50 size

EM = sharpness of separation coefficient

RF = fractional bypass of fines to coarse product

RS = fractional recovery of solids to coarse product

COARSE = weight per cent in each size fraction in coarse product

FINE = weight per cent in each size fraction in fine product.

3.3.7.4 Remarks

All size parameters (XMU, D50C) must be consistent units (e.g., micrometres).

Many of the modules for size separation unit operations utilize a partition curve function to represent the solid–solid separation. One of several mathematical functions to represent a partition curve has the form of the familiar Rosin-Rammler equation. It has been shown (47) that this function represents classification effectively. The function is:

$$Y = (1 - \exp(-1n\ 2(d/d50c)^m))(1 - R_f) + R_f$$

where:

- Y = mass fraction of particles of size d which will be directed to the coarse product
- m = sharpness of separation coefficient
- R_f = fractional bypass to coarse product (for wet classifiers) assumed to be fraction of water recovered to coarse product
- d50c = corrected cut size.

The modules KSCRN, HCONE, GCLASS, and BEND all use this partition function to compute the solid–solid separation. Some of the features of this module are:

1. The arithmetic mean is used to represent each size fraction for the reasons cited in Appendix A.
2. The partition number for the size intervals near the cut point (d50c) uses an averaging routing to prevent sudden shifts of material with small changes of cut size. The average partition number for size fraction i near the d50c is calculated as follows:

$$Y_i = 1/4\,(Y_{d_{i+1}} + 2\,Y_{\bar{d}} + Y_{d_i})$$

where:

Y_x = partition value for size x

d_i = upper bound of size interval

d_{i+1} = lower bound of size interval

$\bar{d}$ = 1/2 $(d_i + d_{i+1})$.

3. To provide number overflow protection, all size fractions with mean sizes greater than 10 times the d50c are automatically set to 1.0 (i.e., all solids are routed to the coarse product).

3.3.8 Subroutine: RDFILE

3.3.8.1 Purpose

To read input data file for each simulator. Data must reside on file No. 5.

3.3.8.2 Usage

CALL RDFILE (NS, NG, NC, FEEDS, FEEDW, FEED, PARAM, OPT, NP, NO).

3.3.8.3 Parameters list

All parameters are as defined in Section 2.3 except:

NP = number of items in vector PARAM

NO = number of items in vector OPT.

3.3.9 Subroutine: UDRIVR

3.3.9.1 Purpose

To interactively modify the default data supplied by subroutine RDFILE (see Section 2.3).

3.3.9.2 Usage

CALL UDRIVR (NS, NG, NC, FEEDS, FEEDW, FEED, PARAM, OPT, NP, NO).

3.3.9.3 Parameters list

As defined for RDFILE.

3.4 DATA STRUCTURE AND SYMBOLISM

The task of defining the appropriate symbolism to be incorporated in this text proved to be quite difficult. It is necessary to weight the values of:

— maintaining consistency with the original references (which, among themselves, may be inconsistent);

— maintaining consistency within the report (i.e., one symbol = one meaning);

— maintaining consistency with the other SPOC reports, which were not accessible at the time this was written;

and strike a suitable compromise. For the most part, the authors have attempted to stress the second value; however, in some cases double definition is inevitable. Considering this and the modularity of the report, the value of a general nomenclature table is questionable. Rather, the symbols are defined at first appearance in any given module documentation. Despite the redundancy this might cause, it serves to improve the readability of the report.

While most of the mineral processing calculations are unidimensional in size, coal solids introduce the added complexity of specific gravity and characteristic assays. That is, to be able to properly simulate a coal preparation unit operation it is necessary to know the distribution of solids with respect to both size and specific gravity. Additionally, it is required to know at least one characteristic assay (usually ash) for each of these elements for the subsequent calculation of product stream quality. The data structure which has been evolved is best illustrated by example. Consider the element,

f_{ijk} of F

where:

i = size interval (1 = coarsest)

j = specific gravity interval (1 = heaviest)

k = characteristic.

For k = 1, this is defined as the primary element, that is the weight per cent of the feed solids contained in the i^{th} size by j^{th} specific gravity interval. For $k > 1$ (say k = 3), this is defined as the k^{th} characteristic (say 2^{nd}). Since the ash assay is almost invariably carried in coal preparation simulation calculations, k = 2 has been reserved for ash. This restriction was superimposed by the liberation calculations associated with subroutine ROTARY. Beyond this, the structure is open, requiring only that the user know which characteristic is being carried. While in principle k is unbounded, subroutine DETOUT expects that k is less than or equal to five. While a distinction is drawn between the primary element and the characteristics of this element, both here and in the component mass balances computed for the model, for convenience in the source documentation, all of the k entries are referred to as characteristics. It is hoped that this shorthand won't cause the reader any inconvenience. The reader is referred to any of the data tables used in *Sample Runs* for those models applicable to coal solids for a concrete example of structure.

3.5 STORAGE REQUIREMENT

Storage requirement is not measured, but depends largely on size of arrays since all modules have at most a few hundred statements.

3.6 MAINTENANCE AND UPDATE

Formal maintenance cannot be assured but various updated versions are foreseen as the SPOC project develops.

All programs have been developed on an AMDAHL 470 VG computer, and tested on a CDC CYBER.

4. OPERATING DOCUMENTATION

All programs have been tested on the CYBER 730 computer of the Computer Science Centre at Energy, Mines and Resources Canada. The Network Operating System/Batch Environment, NOS/BE, or the time-sharing system INTERCOM can be used. A conversion to IBM-PC compatible code under DOS and Microsoft FORTRAN has also been completed.

4.1 OPERATING MESSAGES

Normal system messages are produced by NOS/BE and INTERCOM systems. Subroutine HCONE issues special messages when iterations fail to converge or cyclone blocking conditions are met. Subroutine PART issues a special message when the iteration fails to converge in 30 cycles.

4.2 ERROR RECOVERY

Programs must be restarted on error.

4.3 RUN TIME

Run time is normally a fraction of a second on the CDC CYBER, but depends largely on the convergence speed of iterative computations.

5. SAMPLE RUNS

In the following subsections, sample runs are given for all unit simulators described in this chapter. In each case, the sample run consists of a short preamble followed by a list of input variables and a complete image of an interactive session in which the data file is read and modified as required.

5.1 ROTARY

The data used to validate the SPOC simulation code were taken from a sample in Gottfried's (1) documentation. As shown in the sample run that follows, the results of the SPOC module calculations are identical, with one exception. The exception arises because of the difference in the implementation of the screen module which creates negligible differences in predicted products.

It is worth noting that a similar validation run was attempted against a sample calculation in the Battelle (2) documentation. However, it was impossible to match the results, and it was subsequently shown that the errors were resident in the Battelle calculations.

SIMULATION OF A ROTARY BREAKER (ROTARY)

```
PROGRAM
DESCRIPTION:   THIS IS VALLIANT'S MODEL WHICH SUPPOSES THAT COAL
-----------    IS PROCESSED SERIALLY IN A NUMBER OF TUMBLING
               EVENTS.  EACH EVENT CONSISTS OF COAL BREAKAGE
               FOLLOWED BY SCREENING.  THE MATERIAL REMAINING
               WITHIN THE BREAKER AFTER THE COMBINED BREAKER/
               SCREENING IS THE FEED FOR THE NEXT TUMBLING
               EVENT, AND SO ON.

THE PROGRAMS AND SUBROUTINES REQUIRED:
-------------------------------------

 XROTARY,RDFILE,UDRIVR,ROTARY,ROTOUT,LINEAR,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 (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 SETS
           OF NS RECORDS EACH RECORD HAVING NG VALUES)
          (% weight)

 PARAM  = PARAMETER VECTOR - 1 = LENGTH
                             2 = DIAM
                             3 = HOLE
 LENGTH = BREAKER LENGTH IN METRES
 DIAM   = BREAKER DIAMETER IN METRES
 HOLE   = BREAKER DRUM APERTURE SIZE IN MICROMETRES

 OPT    = OPTION VECTOR      1 = FLAG
 FLAG   = FLAG TO REQUEST DETAILED OUTPUT ON PRODUCT STREAMS
        = 0 :  SUMMARY OUTPUT
        = 1 :  SUMMARY PLUS DETAILED OUTPUT

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

          DATA ENTRY FOR : ROTARY

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

8 8 3 500. 50.
 CHANGE?(Y/N)
n
```

```
 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
4.59 .072 .171 .189 1.017 .207 .99 1.773
14.382 .338 .592 1.156 1.495 1.495 4.033 4.7
8.527 .457 .646 1.264 2.125 1.964 5.649 6.268
4.913 .306 .391 .663 1.258 1.36 3.57 4.556
2.116 .139 .156 .262 .558 .59 1.796 2.591
.975 .075 .09 .145 .305 .34 1.035 2.04
.449 .028 .037 .058 .117 .133 .432 1.047
.51 .034 .068 .068 .17 .17 .68 1.7
84.6 41. 31.5 25. 15.4 7.8 4.4 2.8
82.9 45.7 35.1 26.7 16.7 9.4 4.7 2.9
82.2 42.5 34.2 25.9 16.2 9.7 4.7 2.4
82.9 42. 33. 24.8 15.9 9.6 4.7 2.4
82.2 41. 32.7 23.8 15.4 9.2 4.6 2.2
82.2 41. 32.7 23.8 15.4 9.2 4.6 2.2
83. 41.9 33.6 24.6 15.5 8.9 4.3 1.8
21. 21. 21. 21. 21. 21. 21. 21.
4000. 8417. 9966. 11025. 12590. 13829. 14383. 14644.
4000. 7651. 9379. 10748. 12378. 13568. 14334. 14627.
4000. 8173. 9525. 10878. 12459. 13519. 14334. 14709.
4000. 8254. 9721. 11058. 12508. 13535. 14334. 14709.
4000. 8417. 9770. 11221. 12590. 13600. 14350. 14741.
4000. 8417. 9770. 11221. 12590. 13600. 14350. 14741.
4000. 8270. 9623. 11090. 12574. 13649. 14399. 14807.
11677. 11677. 11677. 11677. 11677. 11677. 11677. 11677.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
6.7056 1.524 152400.
 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:

457200. 304800. 152400. 50800. 25400. 9525. 595. 297.
 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 ROTARY BEAKER (ROTARY)

```
-----------------------------------------------------------------------------------
                                        FEED STREAM
                                        SOLIDS FLOWRATE = 500.0
                                        WATER FLOWRATE  =  50.0
                                               ! ! ! ! ! !
                                               ! ! ! ! ! !
                                               ! ! ! ! ! !
                                               V V V V V V
                                               BBBBBBBBBBB
                                              B     !     B
                                             B      !      B
                                            B       !       B
                                           B                 B
                                          B                   B
                                         B                     B
LENGTH     =      6.7(M)                 B                     B=====> REJECT STREAM
DIAMETER   =      1.5(M)                 B- ----          -----B=====> SOLIDS FLOWRATE=   85.6
HOLE SIZE  =152400.0(MU)                 B                     B=====> WATER FLOWRATE =    0.0
                                         B                     B
                                          B                   B
                                           B                 B
                                            B       !       B
                                             B      !      B
                                              B     !     B
                                               BBBBBBBBBBB
                                               ! ! ! ! ! !
                                               ! ! ! ! ! !
                                               ! ! ! ! ! !
                                               V V V V V V
                                               PRODUCT STREAM
                                               SOLIDS FLOWRATE = 414.6
                                               WATER FLOWRATE  =  50.0
```

SOLIDS DISTRIBUTION

SIZE RANGE	FEED WT. (%)	FEED ASH %	COAL WT. (%)	COAL ASH %	ROCK WT. (%)	ROCK ASH %
457200. - 304800.	9.01	47.51	0.00	0.00	23.89	94.30
304800. - 152400.	28.19	47.21	0.00	0.00	74.61	92.51
152400. - 50800.	26.90	32.35	37.90	28.22	1.50	99.35
50800. - 25400.	17.02	29.99	27.82	24.66	.00	99.22
25400. - 9525.	8.21	26.68	13.91	21.91	.00	99.30
9525. - 595.	5.01	21.32	10.02	16.78	.00	99.03
595. - 297.	2.30	20.80	5.43	15.12	.00	99.20
297. - 0.	3.40	21.00	4.94	18.70	.00	99.72
CUMULATIVE VALUES:	100.03	35.83	100.00	24.03	100.00	93.04

CUMULATIVE CHARACTERISTIC VALUES(NC>2)

CHAR.# 2   FEED=10126.04 COAL=11979.46 ROCK= 1145.65

ROTARY BREAKER REJECT STREAM

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	DIRECT VALUES CHAR. #2	CHAR. #3	CHAR. #4
457200.	- 1.300	.51	2.80	14644.00		
X304800.	- 1.350	.28	4.40	14383.00		
23.89%	- 1.400	.06	7.80	13829.00		
	- 1.500	.29	15.40	12590.00		
	- 1.600	.05	25.00	11025.00		
	- 1.700	.05	31.50	9966.00		
	- 1.800	.02	41.00	8417.00		
	- 2.600	22.62	99.10	233.52		
304800.	- 1.300	1.84	2.87	14631.53		
X152400.	- 1.350	1.43	4.64	14343.36		
74.61%	- 1.400	.49	9.21	13598.67		
	- 1.500	.71	16.19	12461.85		
	- 1.600	.38	26.47	10785.64		
	- 1.700	.22	34.32	9506.63		
	- 1.800	.12	44.90	7781.25		
	- 2.600	69.41	98.70	311.61		
152400.	- 1.300	.00	2.86	14633.73		
X 50800.	- 1.350	.00	4.61	14348.65		
1.50%	- 1.400	.00	9.09	13618.59		
	- 1.500	.00	16.00	12492.81		
	- 1.600	.00	26.32	10809.25		
	- 1.700	.00	33.90	9575.09		
	- 1.800	.00	44.43	7857.84		
	- 2.600	1.49	99.90	25.32		
50800.	- 1.300	.00	2.86	14633.39		
X 25400.	- 1.350	.00	4.62	14347.81		
.00%	- 1.400	.00	9.11	13615.29		
	- 1.500	.00	16.02	12488.43		
	- 1.600	.00	26.35	10805.39		
	- 1.700	.00	33.96	9564.40		
	- 1.800	.00	44.51	7845.56		
	- 2.600	.00	99.87	30.47		
25400.	- 1.300	.00	2.86	14633.33		
X 9525.	- 1.350	.00	4.62	14347.64		
.00%	- 1.400	.00	9.11	13614.65		
	- 1.500	.00	16.03	12487.55		
	- 1.600	.00	26.35	10804.63		
	- 1.700	.00	33.98	9562.29		
	- 1.800	.00	44.52	7843.14		
	- 2.600	.00	99.89	27.32		
9525.	- 1.300	.00	2.86	14633.28		
X 595.	- 1.350	.00	4.62	14347.52		
.00%	- 1.400	.00	9.12	13614.18		
	- 1.500	.00	16.03	12486.89		
	- 1.600	.00	26.36	10804.07		
	- 1.700	.00	33.99	9560.73		
	- 1.800	.00	44.53	7841.36		
	- 2.600	.00	99.84	37.89		

595.	- 1.300	.00	2.86	14633.25
X 297.	- 1.350	.00	4.62	14347.45
.00%	- 1.400	.00	9.12	13613.90
	- 1.500	.00	16.03	12486.50
	- 1.600	.00	26.36	10803.75
	- 1.700	.00	33.99	9559.81
	- 1.800	.00	44.54	7840.31
	- 2.600	.00	99.87	31.08
297.	- 1.300	.00	2.86	14633.24
X 0.	- 1.350	.00	4.62	14347.43
.00%	- 1.400	.00	9.12	13613.81
	- 1.500	.00	16.04	12486.38
	- 1.600	.00	26.36	10803.64
	- 1.700	.00	33.99	9559.51
	- 1.800	.00	44.54	7839.97
	- 2.600	.00	99.95	10.92

CUMULATIVE VALUES

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
457200.	- 1.300	2.14	2.80	14644.00		
X304800.	- 1.350	3.33	3.37	14550.48		
23.89%	- 1.400	3.58	3.68	14500.20		
	- 1.500	4.80	6.67	14012.95		
	- 1.600	5.03	7.50	13877.72		
	- 1.700	5.23	8.44	13723.84		
	- 1.800	5.32	8.97	13637.37		
	- 2.600	100.00	94.30	946.80		
304800.	- 1.300	2.47	2.87	14631.53		
X152400.	- 1.350	4.39	3.65	14505.41		
74.61%	- 1.400	5.05	4.37	14388.01		
	- 1.500	6.00	6.25	14081.81		
	- 1.600	6.51	7.85	13820.82		
	- 1.700	6.81	8.98	13635.94		
	- 1.800	6.96	9.79	13503.91		
	- 2.600	100.00	92.51	1230.25		
152400.	- 1.300	.22	2.86	14633.73		
X 50800.	- 1.350	.38	3.60	14512.54		
1.50%	- 1.400	.43	4.27	14404.79		
	- 1.500	.52	6.32	14070.41		
	- 1.600	.57	7.79	13829.97		
	- 1.700	.59	8.90	13650.02		
	- 1.800	.60	9.66	13525.18		
	- 2.600	100.00	99.35	106.95		
50800.	- 1.300	.26	2.86	14633.39		
X 25400.	- 1.350	.46	3.61	14511.43		
.00%	- 1.400	.52	4.28	14402.17		
	- 1.500	.63	6.31	14072.16		
	- 1.600	.68	7.80	13828.56		
	- 1.700	.71	8.91	13647.85		
	- 1.800	.73	9.68	13521.90		
	- 2.600	100.00	99.22	128.50		

25400.	- 1.300	.24	2.86	14633.33
X 9525.	- 1.350	.41	3.61	14511.22
.00%	- 1.400	.47	4.28	14401.65
	- 1.500	.57	6.30	14072.50
	- 1.600	.61	7.80	13828.28
	- 1.700	.64	8.91	13647.42
	- 1.800	.65	9.69	13521.25
	- 2.600	100.00	99.30	115.31
9525.	- 1.300	.33	2.86	14633.28
X 595.	- 1.350	.57	3.61	14511.05
.00%	- 1.400	.65	4.29	14401.27
	- 1.500	.78	6.30	14072.76
	- 1.600	.84	7.80	13828.07
	- 1.700	.88	8.91	13647.10
	- 1.800	.90	9.69	13520.76
	- 2.600	100.00	99.03	159.51
595.	- 1.300	.27	2.86	14633.25
X 297.	- 1.350	.47	3.61	14510.96
.00%	- 1.400	.53	4.29	14401.05
	- 1.500	.64	6.30	14072.91
	- 1.600	.69	7.80	13827.95
	- 1.700	.73	8.92	13646.91
	- 1.800	.74	9.69	13520.48
	- 2.600	100.00	99.20	131.06
297.	- 1.300	.09	2.86	14633.24
X 0.	- 1.350	.16	3.61	14510.93
.00%	- 1.400	.19	4.29	14400.97
	- 1.500	.23	6.30	14072.96
	- 1.600	.25	7.80	13827.91
	- 1.700	.26	8.92	13646.85
	- 1.800	.26	9.69	13520.39
	- 2.600	100.00	99.72	46.27

ROTARY BREAKER PRODUCT STREAM

				DIRECT VALUES		
SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
457200.	- 1.300	0.00	0.00	0.00		
X304800.	- 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		
304800.	- 1.300	0.00	0.00	0.00		
X152400.	- 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		

152400.	- 1.300	9.23	2.57	14681.97
X 50800.	- 1.350	7.91	4.68	14337.15
37.90%	- 1.400	2.73	9.54	13544.36
	- 1.500	3.29	16.19	12461.58
	- 1.600	1.88	26.10	10846.05
	- 1.700	1.00	34.23	9520.97
	- 1.800	.64	43.25	8051.14
	- 2.600	11.22	72.98	6284.92
50800.	- 1.300	7.54	2.55	14684.75
X 25400.	- 1.350	6.00	4.68	14336.72
27.82%	- 1.400	2.19	9.50	13550.96
	- 1.500	2.38	16.05	12483.74
	- 1.600	1.30	25.58	10930.70
	- 1.700	.74	33.65	9615.75
	- 1.800	.50	42.94	8101.20
	- 2.600	7.16	69.82	7120.31
25400.	- 1.300	4.24	2.38	14711.29
X 9525.	- 1.350	3.14	4.63	14344.77
13.91%	- 1.400	1.07	9.31	13581.75
	- 1.500	1.14	15.79	12525.82
	- 1.600	.59	25.06	11015.23
	- 1.700	.34	33.44	9648.91
	- 1.800	.25	42.21	8220.63
	- 2.600	3.14	68.63	7277.66
9525.	- 1.300	3.62	2.35	14717.22
X 595.	- 1.350	2.29	4.63	14344.51
10.02%	- 1.400	.78	9.32	13579.96
	- 1.500	.80	15.79	12526.45
	- 1.600	.42	25.02	11022.64
	- 1.700	.24	33.40	9656.47
	- 1.800	.18	42.16	8227.93
	- 2.600	1.68	61.20	9006.19
595.	- 1.300	2.19	2.11	14755.72
X 297.	- 1.350	1.21	4.52	14362.41
5.43%	- 1.400	.40	9.21	13598.66
	- 1.500	.40	15.75	12533.56
	- 1.600	.21	25.00	11024.88
	- 1.700	.12	33.51	9637.57
	- 1.800	.09	42.19	8222.93
	- 2.600	.80	60.76	9152.49
297.	- 1.300	2.45	17.92	12178.28
X 0.	- 1.350	1.02	17.79	12200.24
4.94%	- 1.400	.27	18.17	12137.70
	- 1.500	.27	19.77	11876.74
	- 1.600	.11	22.04	11506.90
	- 1.700	.10	23.32	11298.19
	- 1.800	.06	26.36	10802.71
	- 2.600	.67	20.79	12279.55

CUMULATIVE VALUES

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
457200.	- 1.300	0.00	0.00	0.00		
X304800.	- 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		
304800.	- 1.300	0.00	0.00	0.00		
X152400.	- 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		
152400.	- 1.300	24.36	2.57	14681.97		
X 50800.	- 1.350	45.23	3.54	14522.87		
37.90%	- 1.400	52.42	4.36	14388.65		
	- 1.500	61.12	6.05	14114.51		
	- 1.600	66.07	7.55	13869.34		
	- 1.700	68.71	8.57	13702.56		
	- 1.800	70.40	9.41	13566.68		
	- 2.600	100.00	28.22	11411.37		
50800.	- 1.300	27.12	2.55	14684.75		
X 25400.	- 1.350	48.70	3.49	14530.55		
27.82%	- 1.400	56.57	4.33	14394.23		
	- 1.500	65.14	5.87	14142.85		
	- 1.600	69.80	7.19	13928.47		
	- 1.700	72.45	8.16	13770.54		
	- 1.800	74.26	9.00	13632.28		
	- 2.600	100.00	24.66	11956.30		
25400.	- 1.300	30.51	2.38	14711.29		
X 9525.	- 1.350	53.11	3.34	14555.31		
13.91%	- 1.400	60.79	4.10	14432.34		
	- 1.500	68.98	5.48	14206.05		
	- 1.600	73.20	6.61	14022.00		
	- 1.700	75.62	7.47	13882.16		
	- 1.800	77.42	8.28	13750.36		
	- 2.600	100.00	21.91	12288.96		
9525.	- 1.300	36.14	2.35	14717.22		
X 595.	- 1.350	59.01	3.23	14572.77		
10.02%	- 1.400	66.81	3.94	14456.90		
	- 1.500	74.85	5.22	14249.65		
	- 1.600	79.01	6.26	14079.55		
	- 1.700	81.43	7.07	13947.95		
	- 1.800	83.21	7.82	13825.77		
	- 2.600	100.00	16.78	13016.62		

595.	- 1.300	40.29	2.11	14755.72
X 297.	- 1.350	62.66	2.97	14615.30
5.43%	- 1.400	70.08	3.63	14507.67
	- 1.500	77.45	4.79	14319.59
	- 1.600	81.27	5.74	14165.12
	- 1.700	83.52	6.49	14042.73
	- 1.800	85.18	7.18	13929.36
	- 2.600	100.00	15.12	13221.53

297.	- 1.300	49.54	17.92	12178.28
X 0.	- 1.350	70.15	17.89	12184.73
4.94%	- 1.400	75.60	17.91	12181.34
	- 1.500	80.99	18.03	12161.08
	- 1.600	83.28	18.14	12143.11
	- 1.700	85.32	18.26	12122.90
	- 1.800	86.43	18.37	12105.86
	- 2.600	100.00	18.70	12129.43

```
STOP
035100 MAXIMUM EXECUTION FL.
 1.924 CP SECONDS EXECUTION TIME.
```

5.2 VACRSH

The data used to validate the SPOC simulation code were taken from a sample calculation in the Battelle (2) documentation. The results of the SPOC module calculations, as shown in the sample run which follows, are identical, with one exception. The exception arises because the Battelle code does not account for a situation such as was shown in Figure 8. This difference produces negligible differences in the predicted products; however, strictly speaking, the SPOC module is the more correct form.

SIMULATION OF A COAL CRUSHER (VACRSH)

PROGRAM DESCRIPTION: THIS IS VALLIANT'S MODEL WHICH IDENTIFIES THREE CRUSHING ZONES IN COAL BREAKAGE. THE FIRST ZONE CONSISTS OF COARSE MATERIAL WHICH BREAKS COMPLETELY TO ZONES 2 & 3. ZONE 2 CONTAINS MATERIAL GREATER THAN BUT CLOSE TO THE SET SIZE. ZONE 3 CONSISTS OF MATERIAL MUCH FINER THAN THE SET SIZE.

THIS MODEL IS SAID TO BE CAPABLE OF SIMULATING GYRATORY/JAW, SINGLE ROLL, MULTIPLE ROLL OR CAGE MILL CRUSHERS, EITHER IN PRIMARY OR SECONDARY MODE.

PROGRAMS AND SUBROUTINES REQUIRED:

XVACRSH,RDFILE,UDRIVR,VACRSH,VACOUT,LINEAR,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 (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 SETS
          OF NS RECORDS EACH RECORD HAVING NG VALUES)
         (% WEIGHT)

PARAM  = PARAMETER VECTORS - 1 = SET
                             2 = CONST
SET    = CRUSHER SETTING (MICROMETRES)
CONST  = CRUSHER CONSTANT

OPT    = OPTION VECTOR      -  1 = MODE
                               2 = TYPE
                               3 = FLAG
MODE   = 1 FOR PRIMARY CRUSHER
         2 FOR SECONDARY CRUSHER
TYPE   = 1 FOR A CAGE MILL CRUSHER
         2 FOR A SINGLE ROLL CRUSHER
         3 FOR A MULTIPLE ROLL CRUSHER
         4 FOR A GYRATORY/JAW CRUSHER
FLAG   = FLAG TO REQUEST DETAILED OUTPUT ON PRODUCT STREAMS
         0 SUMMARY OUTPUT
         1 SUMMARY PLUS DETAILED OUTPUT

XMU    = VECTOR OF UPPER SIZES FOR THE INTERVALS (MICROMETRES)
SG     = VECTOR OF UPPER BOUNDS OF SPECIFIC GRAVITY INTERVALS
```

DATA ENTRY FOR : VACRSH

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

7 8 3 44.8 2.4
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
.197 0. .001 .001 .001 0. 0. 0.
54.658 2.032 4.879 4.893 3.796 .035 0. 0.
22.14 1.414 1.952 1.893 .566 .034 .003 0.
1.189 .067 .067 .068 .055 .015 .022 .018
0. 0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0. 0.
99.16 44.47 33.93 26.34 16.01 9.12 0. 0.
79.45 42.99 32.75 25.78 15.54 8.62 0. 0.
69.61 43.01 33.81 26.02 15.92 9.35 4.64 0.
75.21 41.92 33.75 25.82 15.75 9.59 4.75 2.47
0. 0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0. 0.
79. 8269. 9723. 11077. 12682. 13909. 0. 0.
2016. 8269. 9723. 11077. 12682. 13909. 0. 0.
2841. 8269. 9723. 11077. 12682. 13909. 14907. 0.
2397. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
0. 0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0. 0.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
6985. 1.7
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE OPTIONS  RELATED TO THIS SIMULATOR ARE:
2. 3. 1.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SIZES ARE:

304800. 152400. 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 OF VALLIANT CRUSHER MODEL (VACRSH)

```
---------------------------------------------------------------------------------
                          FEED STREAM
                          SOLIDS FLOWRATE =    44.8
                          WATER FLOWRATE  =     2.4
                              ! ! ! ! !
                              ! ! ! ! !
                              ! ! ! ! !
                              V V V V V
                        ----------------------
                        I                    I
GAP      = 6985.0(MU)   I                    I
CONSTANT=    1.7        I                    I
SECONDARY CRUSHER       I                    I
MULTIPLE ROLL CRUSHER   I                    I
                        I                    I
                        I                    I
                         V                  V
                          V                V
                           V              V
                            V            V
                            --------------
                              ! ! ! ! !
                              ! ! ! ! !
                              ! ! ! ! !
                              V V V V V
                          PRODUCT STREAM
                          SOLIDS FLOWRATE =    44.8
                          WATER FLOWRATE  =     2.4
```

SOLIDS DISTRIBUTION

SIZE RANGE	FEED WT. FREQ.(%)	FEED ASH IN %	PRODUCT WT. FREQ.(%)	PRODUCT ASH IN %
304800. - 152400.	.20	98.05	0.00	0.00
152400. - 50800.	70.29	67.93	0.00	0.00
50800. - 12700.	28.00	61.66	0.00	0.00
12700. - 2380.	1.50	64.90	19.26	66.22
2380. - 595.	0.00	0.00	52.61	66.23
595. - 149.	0.00	0.00	19.49	66.09
149. - 0.	0.00	0.00	8.63	66.10
CUMULATIVE VALUES:	100.00	66.19	100.00	66.19

CUMULATIVE CHARACTERISTIC VALUES(NC>2)

CHAR.# 2 FEED= 4058.79 PRODUCT= 4058.79

CRUSHER PRODUCT

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	DIRECT VALUES CHAR. #2	CHAR. #3	CHAR. #4
304800.	- 1.300	0.00	0.00	0.00		
X152400.	- 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		
152400.	- 1.300	0.00	0.00	0.00		
X 50800.	- 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		
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	.01	2.47	15355.00		
X 2380.	- 1.350	.01	4.74	14907.00		
19.26%	- 1.400	.02	9.13	13909.00		
	- 1.500	.85	15.59	12682.00		
	- 1.600	1.32	25.84	11077.00		
	- 1.700	1.32	33.06	9723.00		
	- 1.800	.68	42.97	8269.00		
	- 2.600	15.06	76.71	2245.77		
2380.	- 1.300	.01	2.47	15355.00		
X 595.	- 1.350	.01	4.74	14907.00		
52.61%	- 1.400	.04	9.08	13909.00		
	- 1.500	2.33	15.59	12682.00		
	- 1.600	3.61	25.85	11077.00		
	- 1.700	3.63	33.05	9723.00		
	- 1.800	1.84	42.98	8269.00		
	- 2.600	41.13	76.71	2245.52		
595.	- 1.300	.00	2.47	15355.00		
X 149.	- 1.350	.00	4.73	14907.00		
19.49%	- 1.400	.02	9.07	13909.00		
	- 1.500	.85	15.59	12682.00		
	- 1.600	1.34	25.85	11077.00		
	- 1.700	1.35	33.08	9723.00		
	- 1.800	.69	42.98	8269.00		
	- 2.600	15.24	76.49	2263.65		

149.	- 1.300	.00	2.47	15355.00
X 0.	- 1.350	.00	4.73	14907.00
8.63%	- 1.400	.01	9.07	13909.00
	- 1.500	.38	15.59	12682.00
	- 1.600	.59	25.85	11077.00
	- 1.700	.60	33.07	9723.00
	- 1.800	.31	42.98	8269.00
	- 2.600	6.75	76.51	2262.09

CUMULATIVE VALUES

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
304800.	- 1.300	0.00	0.00	0.00		
X152400.	- 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		
152400.	- 1.300	0.00	0.00	0.00		
X 50800.	- 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		
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	.03	2.47	15355.00		
X 2380.	- 1.350	.07	3.76	15099.84		
19.26%	- 1.400	.16	6.88	14409.75		
	- 1.500	4.59	15.29	12741.52		
	- 1.600	11.43	21.60	11746.09		
	- 1.700	18.31	25.90	10986.14		
	- 1.800	21.81	28.65	10549.46		
	- 2.600	100.00	66.22	4057.13		
2380.	- 1.300	.02	2.47	15355.00		
X 595.	- 1.350	.04	3.79	15093.92		
52.61%	- 1.400	.12	7.34	14297.80		
	- 1.500	4.56	15.37	12725.60		
	- 1.600	11.42	21.66	11735.48		
	- 1.700	18.32	25.95	10977.41		
	- 1.800	21.82	28.68	10543.02		
	- 2.600	100.00	66.23	4056.09		

```
    595.  - 1.300           .01    2.47  15355.00
X   149.  - 1.350           .03    3.81  15088.86
 19.49%   - 1.400           .11    7.57  14245.86
          - 1.500          4.48   15.39  12721.80
          - 1.600         11.34   21.72  11726.72
          - 1.700         18.25   26.02  10968.14
          - 1.800         21.80   28.78  10529.18
          - 2.600        100.00   66.09   4065.27
--------------------------------------------------------------------------------
    149.  - 1.300           .01    2.47  15355.00
X     0.  - 1.350           .03    3.82  15087.26
  8.63%   - 1.400           .11    7.64  14228.77
          - 1.500          4.48   15.40  12720.10
          - 1.600         11.35   21.72  11726.14
          - 1.700         18.26   26.02  10967.84
          - 1.800         21.80   28.77  10529.55
          - 2.600        100.00   66.10   4064.36
--------------------------------------------------------------------------------
     STOP
     041400 MAXIMUM EXECUTION FL.
      0.952 CP SECONDS EXECUTION TIME.
```

5.3 KSCRN

The data for the source code verification are taken from the sample calculation presented by Karra (3). The data are as follows:

Size of screen: 1.52 × 3.66 m
AREA = 5.563 m^2

Aperture: 15.9 mm (Top Deck)

Wire diameter: 4.88 mm

Feed: 103 tonnes/h (dry)

Screen angle: 20 degrees

Specific gravity of solids: 2.67

The feed size analysis was:

Interval top size (μm)	Weight per cent
18 800	6.32
15 900	14.00
12 700	20.42
9 530	6.84
7 940	7.11
6 680	10.74
4 700	7.42
3 350	5.68
2 360	21.47
	100.00

As can be observed, the module KSCRN using this data produced a solids split of 20.84 t/h to the oversize compared with Karra's calculated value of 20.77 t/h (see sample run which follows). The size analyses of the oversize and undersize products also only differ from Karra's values in the third significant figure. The small differences are due to the fact that Karra used the geometric mean sizes rather than the arithmetic mean.

KARRA'S SCREEN MODEL (KSCRN)

PROGRAM DESCRIPTION: THIS MODEL INCORPORATES ALL THE PARAMETERS WHICH ARE DEEMED SIGNIFICANT IN EVALUATING A SCREEN'S PERFORMANCE. THE MODEL RELATIONSHIPS WERE ESTABLISHED FROM DATA OBTAINED FROM 20 DRY SCREENING TESTS ON 1.5 X 1.7 M TEST PLANT VIBRATING SCREEN WITH FEED RATE FROM 100 TO 300 TONNES/HR AND APERTURE SIZE FROM 5 TO 50 MM

THE PROGRAMS AND SUBROUTINES REQUIRED:

XKSCRN,RDFILE,UDRIVR,KSCRN,KAROUT,PART,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     = SRFD = MASS FLOW RATE OF SOLIDS IN FEED (TONNES/HR)
WAT     = WRFD = 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 SETS
           OF NS RECORDS EACH RECORD HAVING NG VALUES)
          (% WEIGHT)

PARAM    = PARAMETER VECTOR   -   1 = BYPASS
                                  2 = CAP
                                  3 = WATOF
                                  4 = EM
                                  5 = APER
                                  6 = ANGLE
                                  7 = WIRE
                                  8 = DECK
                                  9 = AREA
                                 10 = WET
BYPASS   = FRACTION OF FINES BYPASSED TO COARSE DUE TO STICKING
CAP      = CAPACITY CORRECTION FACTOR TO ADJUST D50 CORRELATION
WATOF    = PERCENT MOISTURE IN OVERSIZE STREAM
EM       = SHARPNESS OF SEPARATION FACTOR (DEFAULT = 5.846)
APER     = MINIMUM SCREEN OPENING (MICROMETRES)
ANGLE    = ANGLE OF SCREEN TO THE HORIZONTAL (DEGREES)
WIRE     = WIRE DIAMETER (MICROMETRES), SET TO 0.0 FOR SLOTTED OR
           NON-SQUARE SCREENS
DECK     = POSITION OF SCREEN IN MULTIPLE DECK SCREEN
           (TOP = 1:  SECOND = 2: ETC.)
AREA     = AREA OF SCREEN SURFACE (SQ. METRES)
WET      = TONNES/HR OF WATER ADDED THROUGH SPRAYS
           (TYPICAL VALUES = 0.015 TO .025 * SOL)

OPT      = OPTION VECTOR       - 1 = FLAG
FLAG     = FLAG TO REQUEST DETAILED OUTPUT ON PRODUCT STREAMS
         = 0:   SUMMARY OUTPUT
         = 1:   SUMMARY PLUS DETAILED OUTPUT
```

```
   XMU     = PASSING SIZE FROM COARSE TO FINE (MICROMETRES)
   SG      = VECTOR OF UPPER SPECIFIC GRAVITIES FOR
             THE INTERVALS


              DATA ENTRY FOR : KSCRN


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

9 1 1 103. 0.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
6.32 14. 20.42 6.84 7.11 10.74 7.42 5.68 21.47
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
0. 1. 0. 0. 15900. 20. 4880. 1. 5.5632 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:

18800. 15900. 12700. 9530. 7940. 6680. 4700. 3330. 2360.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SPECIFIC GRAVITIES ARE:
2.67
 CHANGE?(Y/N)
n
```

OUTPUT FROM KARRA SCREEN (KSCRN)

```
--------------------------------------------------------------------------------

                      ALL MASS FLOWRATES IN TONNES/HOUR

                              FEED STREAM
                              SOLIDS FLOWRATE= 103.0
                              WATER FLOWRATE =   0.0
                              !   !  !   !  !   !
                              !   !  !   !  !   !
                              !   !  !   !  !   !
                              V   V  V   V  V   V
APERTURE=15900.00(MU)
WIRE SIZE= 4880.00(MU)                                     =========="
                                                           ========= "
AREA  =  5.56(SQ M)     - -- -- -- -- -- -- -- -- -- --          " "
%WATER(O/S)=  0.00                                                 " "
BYPASS=  0.00                                                      " "
                              !   !  !   !  !   !                  " "
                              !   !  !   !  !   !                  " "
                              !   !  !   !  !   !                  " "
                              V   V  V   V  V   V                  V V
                              UNDERSIZE PRODUCT            OVERSIZE PRODUCT
                              SOLIDS FLOWRATE= 82.16       SOLIDS FLOWRATE= 20.84
                              WATER FLOWRATE =  0.00       WATER FLOWRATE =  0.00
```

SOLIDS DISTRIBUTION

SIZE RANGE	FEED WT. (%)	FEED ASH %	UNDER WT. (%)	UNDER ASH %	OVER WT. (%)	OVER ASH %
18800. - 15900.	6.32	0.00	.32	0.00	29.96	0.00
15900. - 12700.	14.00	0.00	6.39	0.00	44.02	0.00
12700. - 9530.	20.42	0.00	19.73	0.00	23.13	0.00
9530. - 7940.	6.84	0.00	8.09	0.00	1.90	0.00
7940. - 6680.	7.11	0.00	8.73	0.00	.71	0.00
6680. - 4700.	10.74	0.00	13.40	0.00	.25	0.00
4700. - 3330.	7.42	0.00	9.30	0.00	.02	0.00
3330. - 2360.	5.68	0.00	7.12	0.00	.00	0.00
2360. - 0.	21.47	0.00	26.92	0.00	.00	0.00
CUMULATIVE VALUES:	100.00		100.00		100.00	

SCREEN OVERSIZE STREAM

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
				DIRECT VALUES		
18800.	- 2.670	29.96				
15900.	- 2.670	44.02				
12700.	- 2.670	23.13				
9530.	- 2.670	1.90				
7940.	- 2.670	.71				
6680.	- 2.670	.25				
4700.	- 2.670	.02				
3330.	- 2.670	.00				
2360.	- 2.670	.00				

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
				CUMULATIVE VALUES		
18800.	- 2.670	100.00				
15900.	- 2.670	100.00				
12700.	- 2.670	100.00				
9530.	- 2.670	100.00				
7940.	- 2.670	100.00				
6680.	- 2.670	100.00				
4700.	- 2.670	100.00				
3330.	- 2.670	100.00				
2360.	- 2.670	100.00				

SCREEN UNDERSIZE STREAM

DIRECT VALUES

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
18800.	- 2.670	.32				
15900.	- 2.670	6.39				
12700.	- 2.670	19.73				
9530.	- 2.670	8.09				
7940.	- 2.670	8.73				
6680.	- 2.670	13.40				
4700.	- 2.670	9.30				
3330.	- 2.670	7.12				
2360.	- 2.670	26.92				

CUMULATIVE VALUES

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
18800.	- 2.670	100.00				
15900.	- 2.670	100.00				
12700.	- 2.670	100.00				
9530.	- 2.670	100.00				
7940.	- 2.670	100.00				
6680.	- 2.670	100.00				
4700.	- 2.670	100.00				
3330.	- 2.670	100.00				
2360.	- 2.670	100.00				

STOP
042400 MAXIMUM EXECUTION FL.
0.917 CP SECONDS EXECUTION TIME.

5.4 WSCRN

The source code validation for this SPOC module was performed on the data provided in Lynch's (6) text (Example 7, p. 133) and observed to give identical results. The first sample run shows the results from these data.

Since this module is offered as an alternative to Valliant's model (see next section), it was also run using the data taken from a sample calculation in the Battelle (2) documentation which was used to validate the SPOC module for Valliant's model. This output is shown in the second sample run. Some of the parameters were "pulled out of the air". The similarity of the predicted results can be judged by the reader.

WHITEN'S SCREEN MODEL (WSCRN)

```
PROGRAM
DESCRIPTION:    THIS MODEL HAS BEEN USED IN THE SIMULATION OF
-----------     COARSE SCREENS IN MINERAL CRUSHING PLANTS.
                IT IS CONSIDERED AS AN ALTERNATIVE TO THE VALLIANT
                MODEL FOR COAL SCREENING.  THE MODEL COMPUTES THE
                MEAN PROBABILITY THAT PARTICLES WITHIN A NARROW
                SIZE INTERVAL WILL REPORT TO THE SCREEN OVERSIZE
                PRODUCT.  PARTICLES SMALLER THAN THE APERTURE
                HAVE THEIR PROBABILITY COMPUTED AS A FUNCTION OF
                PARTICLE SIZE, APERTURE SIZE, SCREEN WIRE SIZE,
                SCREEN EFFICENCY, SCREEN LOADING AND SCREEN LENGTH.
```

THE PROGRAMS AND SUBROUTINES REQUIRED ARE:

XWSCRN,RDFILE,UDRIVR,WSCRN,WHSOUT,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 (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 SETS
           OF NS RECORDS EACH RECORD HAVING NG VALUES)
          (% WEIGHT)

PARAM   = PARAMETER VECTOR - 1 = APER
                             2 = WIRE
                             3 = EFF
                             4 = DIST
                             5 = FACT
                             6 = BYPASS
                             7 = WATOF
APER    = SCREEN THROUGHFALL APERTURE (NOT CORRECTED FOR
          INCLINATION)
WIRE    = SCREEN WIRE DIAMETER (MICROMETRES)
EFF     = EFFICIENCY FACTOR
DIST    = SCREEN LENGTH IN METRES
FACT    = LOAD FACTOR
BYPASS  = FRACTION OF SUBMESH MATERIAL WHICH REPORTS TO OVERSIZE
WATOF   = % MOISTURE IN OVERSIZE

OPT     = OPTION VECTOR     - 1 = FLAG
FLAG    = FLAG TO REQUEST DETAILED OUTPUT ON PRODUCT STREAMS
        = 0 :  SUMMARY OUTPUT
        = 1 :  SUMMARY PLUS DETAILED OUTPUT

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

```
                DATA ENTRY FOR : WSCRN(LYNCH)

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

8 1 1 257. 30.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
9.16 10.17 19.67 26.89 11.53 8.6 6.31 7.67
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
12700. 2500. 2.79 6.4 1. .1 10.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE OPTIONS  RELATED TO THIS SIMULATOR ARE:
0.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SIZES ARE:

45250. 22630. 16000. 11314. 5660. 2830. 1000. 250.
 CHANGE?(Y/N)
n

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

OUTPUT FROM WHITEN SCREEN (WSCRN)

```
                                             FEED STREAM
                                             SOLIDS FLOWRATE= 257.0
                                             WATER FLOWRATE =  30.0
                                             !   !  !   !  !   !
                                             !   !  !   !  !   !
                                             !   !  !   !  !   !
                                             V   V  V   V  V   V
   LOAD FACT.=  1.00
   APERTURE=12700.00(MU)
   WIRE SIZE= 2500.00(MU)                                             ==========*
   EFF.  =   2.79          _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ ========= *
   LENGTH=  6.40(M)                                                          * *
   %WATER(O/S)= 10.00                                                        * *
   BYPASS=    .10                                                            * *
                                             !   !  !   !  !   !             * *
                                             !   !  !   !  !   !             * *
                                             !   !  !   !  !   !             * *
                                             V   V  V   V  V   V             V V
                                             UNDERSIZE PRODUCT      OVERSIZE PRODUCT
                                             SOLIDS FLOWRATE=148.12 SOLIDS FLOWRATE=108.88
                                             WATER FLOWRATE = 17.90 WATER FLOWRATE = 12.10
```

SOLIDS DISTRIBUTION

SIZE RANGE	FEED WT. (%)	FEED ASH %	UNDER WT. (%)	UNDER ASH %	OVER WT. (%)	OVER ASH %
45250. - 22630.	9.16	0.00	0.00	0.00	21.62	0.00
22630. - 16000.	10.17	0.00	0.00	0.00	24.01	0.00
16000. - 11314.	19.67	0.00	1.08	0.00	44.96	0.00
11314. - 5660.	26.89	0.00	41.12	0.00	7.53	0.00
5660. - 2830.	11.53	0.00	19.97	0.00	.05	0.00
2830. - 1000.	8.60	0.00	14.91	0.00	.01	0.00
1000. - 250.	6.31	0.00	10.94	0.00	.01	0.00
250. - 0.	7.67	0.00	11.98	0.00	1.81	0.00
CUMULATIVE VALUES:	100.00		100.00		100.00	

STOP
042100 MAXIMUM EXECUTION FL.
0.374 CP SECONDS EXECUTION TIME.

```
DATA ENTRY FOR : WSCRN

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

5 8 3 208.6 30.
 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 43.01 33.81 26.02 15.92 9.35 4.64 2.62
75.21 41.92 33.75 25.82 15.75 9.59 4.75 2.47
75.68 41.88 33.46 25.02 15.56 9.05 4.44 1.95
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:
12700. 2500. 2.79 6.4 1. 0. 10.
 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:

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 WHITEN SCREEN (WSCRN)

```
-----------------------------------------------------------------------------
                                  FEED STREAM
                                  SOLIDS FLOWRATE= 208.6
                                  WATER FLOWRATE =  30.0
                                  !   !  !   !  !   !
                                  !   !  !   !  !   !
                                  !   !  !   !  !   !
                                  V   V  V   V  V   V
  LOAD FACT.=  1.00
  APERTURE=12700.00(MU)
  WIRE SIZE= 2500.00(MU)                                   ==========*
  EFF.  =  2.79              _ _ _ _ _ _ _ _ _ _ _ _       ========= *
  LENGTH=  6.40(M)                                                 * *
  %WATER(O/S)= 10.00                                               * *
  BYPASS=  0.00                                                    * *
                                  !   !  !   !  !   !              * *
                                  !   !  !   !  !   !              * *
                                  !   !  !   !  !   !              * *
                                  V   V  V   V  V   V              V V
                                  UNDERSIZE PRODUCT         OVERSIZE PRODUCT
                                  SOLIDS FLOWRATE=132.39    SOLIDS FLOWRATE= 76.21
                                  WATER FLOWRATE = 21.53    WATER FLOWRATE =  8.47
```

SOLIDS DISTRIBUTION

SIZE RANGE	FEED		UNDER		OVER	
	WT. (%)	ASH %	WT. (%)	ASH %	WT. (%)	ASH %
50800. - 12700.	29.68	27.28	0.00	0.00	81.23	27.28
12700. - 2380.	36.91	22.75	47.37	22.75	18.73	22.75
2380. - 595.	15.90	17.94	25.04	17.94	.02	17.94
595. - 149.	9.20	12.44	14.49	12.44	.01	12.44
149. - 0.	8.50	11.53	13.39	11.53	0.00	0.00
CUMULATIVE VALUES:	100.18	21.43	100.29	18.56	100.00	26.43

CUMULATIVE CHARACTERISTIC VALUES(NC>2)

CHAR.# 2   FEED=11779.15 COAL=12282.93 ROCK=10901.59

SCREEN OVERSIZE STREAM

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	DIRECT VALUES CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	20.33	2.62	15355.00		
X 12700.	- 1.350	16.27	4.64	14907.00		
81.23%	- 1.400	5.26	9.35	13909.00		
	- 1.500	8.05	15.92	12682.00		
	- 1.600	3.75	26.02	11077.00		
	- 1.700	2.06	33.81	9723.00		
	- 1.800	1.27	43.01	8269.00		
	- 2.600	24.26	69.61	2841.00		
12700.	- 1.300	6.05	2.47	15355.00		
X 2380.	- 1.350	4.26	4.75	14907.00		
18.73%	- 1.400	1.37	9.59	13909.00		
	- 1.500	1.55	15.75	12682.00		
	- 1.600	.69	25.82	11077.00		
	- 1.700	.39	33.75	9723.00		
	- 1.800	.29	41.92	8269.00		
	- 2.600	4.13	75.21	2397.00		
2380.	- 1.300	.01	1.95	15355.00		
X 595.	- 1.350	.01	4.44	14907.00		
.02%	- 1.400	.00	9.05	13909.00		
	- 1.500	.00	15.56	12682.00		
	- 1.600	.00	25.02	11077.00		
	- 1.700	.00	33.46	9723.00		
	- 1.800	.00	41.88	8269.00		
	- 2.600	.00	75.68	2272.00		
595.	- 1.300	.01	1.86	15355.00		
X 149.	- 1.350	.00	5.61	14907.00		
.01%	- 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	0.00	1.43	15355.00		
X 0.	- 1.350	0.00	3.21	14907.00		
0.00%	- 1.400	0.00	4.86	13909.00		
	- 1.500	0.00	12.16	12682.00		
	- 1.600	0.00	19.47	11077.00		
	- 1.700	0.00	26.63	9723.00		
	- 1.800	0.00	35.16	8269.00		
	- 2.600	0.00	62.19	2027.00		

		CUMULATIVE VALUES				
SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	25.03	2.62	15355.00		
X 12700.	- 1.350	45.06	3.52	15155.86		
81.23%	- 1.400	51.52	4.25	14999.31		
	- 1.500	61.43	6.13	14625.52		
	- 1.600	66.05	7.52	14377.70		
	- 1.700	68.58	8.49	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		
18.73%	- 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	1.95	15355.00		
X 595.	- 1.350	64.67	2.75	15211.24		
.02%	- 1.400	71.02	3.31	15094.76		
	- 1.500	77.23	4.30	14900.80		
	- 1.600	80.10	5.04	14763.87		
	- 1.700	81.82	5.64	14658.07		
	- 1.800	83.10	6.20	14558.94		
	- 2.600	100.00	17.94	12483.03		
595.	- 1.300	54.75	1.86	15355.00		
X 149.	- 1.350	70.17	2.68	15256.52		
.01%	- 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	0.00	0.00	0.00		
X 0.	- 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		

SCREEN UNDERSIZE STREAM

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	DIRECT VALUES CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	0.00	2.62	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	43.01	8269.00		
	- 2.600	0.00	69.61	2841.00		
12700.	- 1.300	15.30	2.47	15355.00		
X 2380.	- 1.350	10.78	4.75	14907.00		
47.37%	- 1.400	3.48	9.59	13909.00		
	- 1.500	3.91	15.75	12682.00		
	- 1.600	1.74	25.82	11077.00		
	- 1.700	.99	33.75	9723.00		
	- 1.800	.73	41.92	8269.00		
	- 2.600	10.43	75.21	2397.00		
2380.	- 1.300	11.00	1.95	15355.00		
X 595.	- 1.350	5.20	4.44	14907.00		
25.04%	- 1.400	1.59	9.05	13909.00		
	- 1.500	1.55	15.56	12682.00		
	- 1.600	.72	25.02	11077.00		
	- 1.700	.43	33.46	9723.00		
	- 1.800	.32	41.88	8269.00		
	- 2.600	4.23	75.68	2272.00		
595.	- 1.300	7.93	1.86	15355.00		
X 149.	- 1.350	2.24	5.61	14907.00		
14.49%	- 1.400	1.17	8.52	13909.00		
	- 1.500	.74	15.55	12682.00		
	- 1.600	.35	23.81	11077.00		
	- 1.700	.19	30.71	9723.00		
	- 1.800	.12	38.13	8269.00		
	- 2.600	1.75	64.40	2285.00		
149.	- 1.300	5.51	1.43	15355.00		
X 0.	- 1.350	3.02	3.21	14907.00		
13.39%	- 1.400	1.85	4.86	13909.00		
	- 1.500	.76	12.16	12682.00		
	- 1.600	.32	19.47	11077.00		
	- 1.700	.15	26.63	9723.00		
	- 1.800	.09	35.16	8269.00		
	- 2.600	1.69	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		
47.37%	- 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	1.95	15355.00		
X 595.	- 1.350	64.67	2.75	15211.24		
25.04%	- 1.400	71.02	3.31	15094.76		
	- 1.500	77.23	4.30	14900.80		
	- 1.600	80.10	5.04	14763.87		
	- 1.700	81.82	5.64	14658.07		
	- 1.800	83.10	6.20	14558.94		
	- 2.600	100.00	17.94	12483.03		
595.	- 1.300	54.75	1.86	15355.00		
X 149.	- 1.350	70.17	2.68	15256.52		
14.49%	- 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		
13.39%	- 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
042100 MAXIMUM EXECUTION FL.
1.137 CP SECONDS EXECUTION TIME.

5.5 VSCRN

The data on which the SPOC module was validated were taken from a sample calculation in the Battelle documentation and, as shown in the first sample run, the results are essentially identical. The slight differences which are observed arise from the difference in the implementation of the screen model. It is useful to compare these results with those obtained using WSCRN on the same data.

An additional run was made with this model using the WSCRN validation information. The results are shown in the second sample run and the interested reader should compare them with those obtained using WSCRN.

```
                VALLIANT'S SCREEN MODEL (VSCRN)
                -------------------------------
PROGRAM
DESCRIPTION:   THIS IS A RELATIVELY SIMPLE MODEL FOR COARSE
-----------    SCREENING REQUIRING A MINIMUM OF USER INPUT.
               IT IS CAPABLE OF SIMULATING BOTH WET AND DRY
               SCREENING FOR BOTH TOP AND BOTTOM DECKS AND
               FOR PROJECTED THROUGHFALL APERTURES FROM
               18 TO .01 IN.

THE PROGRAMS AND SUBROUTINES REQUIRED:
-------------------------------------

 XVSCRN,RDFILE,UDRIVR,VSCRN,VASOUT,LINEAR,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 (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 SETS
            OF NS RECORDS EACH RECORD HAVING NG VALUES)
           (% WEIGHT)

 PARAM   = PARAMETER VECTOR - 1 = APER
                              2 = ANGLE
                              3 = WATOF
 APER    = SCREEN THROUGHFALL APERTURE (NOT CORRECTED FOR
           INCLINATION)
 ANGLE   = ANGLE OF INCLINATION OF SCREEN (DEG)
 WATOF   = % MOISTURE IN OVERSIZE PRODUCT

 OPT     = OPTION VECTOR    - 1 = FLAG
                              2 = MODE
                              3 = LOCAT
 FLAG    = FLAG TO REQUEST DETAILED OUTPUT ON PRODUCT STREAM
 MODE    = 1 FOR A DRY SCREEN
           2 FOR A WET SCREEN
 LOCAT   = 1 FOR THE TOP DECK
           2 FOR THE BOTTOM DECK

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

```
                 DATA ENTRY FOR : VSCRN

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

5 8 3 208.6 30.
 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 43.01 33.81 26.02 15.92 9.35 4.64 2.62
75.21 41.92 33.75 25.82 15.75 9.59 4.75 2.47
75.68 41.88 33.46 25.02 15.56 9.05 4.44 1.95
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:
12700. 0. 10.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE OPTIONS  RELATED TO THIS SIMULATOR ARE:
1. 2. 2.
 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
```

OUTPUT FROM VALLIANT SCREEN (VSCRN)

```
------------------------------------------------------------------------------------
                                          FEED STREAM
                                          SOLIDS FLOWRATE= 208.6
                                          WATER FLOWRATE=   30.0
                                          !   !  !   !  !   !
                                          !   !  !   !  !   !
                                          !   !  !   !  !   !
                                          V   V  V   V  V   V
APERTURE=12700.00(MU)
ANGLE=   0.00                                                              ==========="
WET SCREEN                                                                 ========== "
LOWER DECK              _ __ __ __ __ __ __ __ __ __ __ __                         " "
%WATER(O/S)= 10.00                                                                 " "
                                          !   !  !   !  !   !                      " "
                                          !   !  !   !  !   !                      " "
                                          !   !  !   !  !   !                      " "
                                          V   V  V   V  V   V                      V V
                                          UNDERSIZE PRODUCT          OVERSIZE PRODUCT
                                          SOLIDS FLOWRATE=132.82     SOLIDS FLOWRATE= 75.78
                                          WATER FLOWRATE= 21.58      WATER FLOWRATE=  8.42
```

SOLIDS DISTRIBUTION

SIZE RANGE	FEED WT. (%)	FEED ASH %	UNDER WT. (%)	UNDER ASH %	OVER WT. (%)	OVER ASH %
50800. - 12700.	29.68	27.28	0.00	0.00	81.70	27.28
12700. - 2380.	36.91	22.75	47.61	22.75	18.14	22.75
2380. - 595.	15.90	17.94	24.91	17.94	.11	17.94
595. - 149.	9.20	12.44	14.43	12.44	.03	12.44
149. - 0.	8.50	11.53	13.34	11.53	.03	11.53
CUMULATIVE VALUES:	100.18	21.43	100.29	18.58	100.00	26.44

CUMULATIVE CHARACTERISTIC VALUES(NC>2)

CHAR.# 2 FEED=11779.15 COAL=12280.23 ROCK=10898.40

SCREEN OVERSIZE STREAM

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	DIRECT VALUES CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	20.45	2.62	15355.00		
X 12700.	- 1.350	16.36	4.64	14907.00		
81.70%	- 1.400	5.29	9.35	13909.00		
	- 1.500	8.10	15.92	12682.00		
	- 1.600	3.77	26.02	11077.00		
	- 1.700	2.07	33.81	9723.00		
	- 1.800	1.27	43.01	8269.00		
	- 2.600	24.39	69.61	2841.00		
12700.	- 1.300	5.86	2.47	15355.00		
X 2380.	- 1.350	4.13	4.75	14907.00		
18.14%	- 1.400	1.33	9.59	13909.00		
	- 1.500	1.50	15.75	12682.00		
	- 1.600	.67	25.82	11077.00		
	- 1.700	.38	33.75	9723.00		
	- 1.800	.28	41.92	8269.00		
	- 2.600	4.00	75.21	2397.00		
2380.	- 1.300	.05	1.95	15355.00		
X 595.	- 1.350	.02	4.44	14907.00		
.11%	- 1.400	.01	9.05	13909.00		
	- 1.500	.01	15.56	12682.00		
	- 1.600	.00	25.02	11077.00		
	- 1.700	.00	33.46	9723.00		
	- 1.800	.00	41.88	8269.00		
	- 2.600	.02	75.68	2272.00		
595.	- 1.300	.02	1.86	15355.00		
X 149.	- 1.350	.00	5.61	14907.00		
.03%	- 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	.01	1.43	15355.00		
X 0.	- 1.350	.01	3.21	14907.00		
.03%	- 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		

SIZE INTERVAL	SPEC. GRAV.	CUMULATIVE VALUES WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
50800.	- 1.300	25.03	2.62	15355.00		
X 12700.	- 1.350	45.06	3.52	15155.86		
81.70%	- 1.400	51.52	4.25	14999.31		
	- 1.500	61.43	6.13	14625.52		
	- 1.600	66.05	7.52	14377.70		
	- 1.700	68.58	8.49	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		
18.14%	- 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	1.95	15355.00		
X 595.	- 1.350	64.67	2.75	15211.24		
.11%	- 1.400	71.02	3.31	15094.76		
	- 1.500	77.23	4.30	14900.80		
	- 1.600	80.10	5.04	14763.87		
	- 1.700	81.82	5.64	14658.07		
	- 1.800	83.10	6.20	14558.94		
	- 2.600	100.00	17.94	12483.03		
595.	- 1.300	54.75	1.86	15355.00		
X 149.	- 1.350	70.17	2.68	15256.52		
.03%	- 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		
.03%	- 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	0.00	2.62	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	43.01	8269.00		
	- 2.600	0.00	69.61	2841.00		
12700.	- 1.300	15.38	2.47	15355.00		
X 2380.	- 1.350	10.83	4.75	14907.00		
47.61%	- 1.400	3.49	9.59	13909.00		
	- 1.500	3.93	15.75	12682.00		
	- 1.600	1.75	25.82	11077.00		
	- 1.700	.99	33.75	9723.00		
	- 1.800	.74	41.92	8269.00		
	- 2.600	10.49	75.21	2397.00		
2380.	- 1.300	10.94	1.95	15355.00		
X 595.	- 1.350	5.17	4.44	14907.00		
24.91%	- 1.400	1.58	9.05	13909.00		
	- 1.500	1.55	15.56	12682.00		
	- 1.600	.71	25.02	11077.00		
	- 1.700	.43	33.46	9723.00		
	- 1.800	.32	41.88	8269.00		
	- 2.600	4.21	75.68	2272.00		
595.	- 1.300	7.90	1.86	15355.00		
X 149.	- 1.350	2.23	5.61	14907.00		
14.43%	- 1.400	1.17	8.52	13909.00		
	- 1.500	.73	15.55	12682.00		
	- 1.600	.35	23.81	11077.00		
	- 1.700	.19	30.71	9723.00		
	- 1.800	.12	38.13	8269.00		
	- 2.600	1.74	64.40	2285.00		
149.	- 1.300	5.49	1.43	15355.00		
X 0.	- 1.350	3.00	3.21	14907.00		
13.34%	- 1.400	1.84	4.86	13909.00		
	- 1.500	.75	12.16	12682.00		
	- 1.600	.32	19.47	11077.00		
	- 1.700	.15	26.63	9723.00		
	- 1.800	.08	35.16	8269.00		
	- 2.600	1.69	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		
47.61%	- 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	1.95	15355.00		
X 595.	- 1.350	64.67	2.75	15211.24		
24.91%	- 1.400	71.02	3.31	15094.76		
	- 1.500	77.23	4.30	14900.80		
	- 1.600	80.10	5.04	14763.87		
	- 1.700	81.82	5.64	14658.07		
	- 1.800	83.10	6.20	14558.94		
	- 2.600	100.00	17.94	12483.03		
595.	- 1.300	54.75	1.86	15355.00		
X 149.	- 1.350	70.17	2.68	15256.52		
14.43%	- 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		
13.34%	- 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
042300 MAXIMUM EXECUTION FL.
 1.143 CP SECONDS EXECUTION TIME.
```

```
              DATA ENTRY FOR : VSCRN(LYNCH)

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

8 1 1 257. 30.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
9.16 10.17 19.67 26.89 11.53 8.6 6.31 7.67
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
12700. 0. 10.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE OPTIONS  RELATED TO THIS SIMULATOR ARE:
0. 1. 1.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SIZES ARE:

45250. 22630. 16000. 11314. 5660. 2830. 1000. 250.
 CHANGE?(Y/N)
n

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

OUTPUT FROM VALLIANT SCREEN (VSCRN)

```
-----------------------------------------------------------------------------------
                              FEED STREAM
                              SOLIDS FLOWRATE= 257.0
                              WATER FLOWRATE=   30.0
                              !   !  !   !  !   !
                              !   !  !   !  !   !
                              !   !  !   !  !   !
                              V   V  V   V  V   V
APERTURE=12700.00(MU)
ANGLE=  0.00                                                 ==========*
DRY SCREEN                                                   ========= *
UPPER DECK              - - - - - - - - - - - - - - - -              * *
%WATER(O/S)= 10.00                                                   * *
                              !   !  !   !  !   !                    * *
                              !   !  !   !  !   !                    * *
                              !   !  !   !  !   !                    * *
                              V   V  V   V  V   V                    V V
                              UNDERSIZE PRODUCT          OVERSIZE PRODUCT
                              SOLIDS FLOWRATE=153.67     SOLIDS FLOWRATE=103.33
                              WATER FLOWRATE= 18.52      WATER FLOWRATE= 11.48
```

SOLIDS DISTRIBUTION

SIZE RANGE	FEED WT. (%)	FEED ASH %	UNDER WT. (%)	UNDER ASH %	OVER WT. (%)	OVER ASH %
45250. - 22630.	9.16	0.00	0.00	0.00	22.78	0.00
22630. - 16000.	10.17	0.00	0.00	0.00	25.29	0.00
16000. - 11314.	19.67	0.00	3.24	0.00	44.10	0.00
11314. - 5660.	26.89	0.00	39.85	0.00	7.62	0.00
5660. - 2830.	11.53	0.00	19.18	0.00	.16	0.00
2830. - 1000.	8.60	0.00	14.37	0.00	.03	0.00
1000. - 250.	6.31	0.00	10.55	0.00	.01	0.00
250. - 0.	7.67	0.00	12.82	0.00	.01	0.00
CUMULATIVE VALUES:	100.00		100.00		100.00	

STOP
042300 MAXIMUM EXECUTION FL.
0.358 CP SECONDS EXECUTION TIME.

5.6 BEND

The data for the source code verification are drawn from Leonard (14). The data are as follows:

Slot width SW: 700 μm

Feed rate SRFD: 15 tonnes/h (assumed)

Per cent solids in feed: 30

Feed size analysis:

Interval top size (μm)	Weight per cent
4 760	56.0
2 380	17.0
1 190	7.0
595	6.5
297	4.5
149	9.0
	100.00

Using the module BEND, the operation of a sieve bend was simulated (see sample run output). A comparison of the results with the actual reported results in Leonard are summarized below:

	Actual	Module BEND
Recovery of solids to oversize	87.6	91.0
Per cent solids in oversize	75.6	70.0
Per cent solids in undersize	5.6	4.1

As can be observed, the module produces a water and solids split very close to that obtained in practice.

SIMULATION OF A SIEVE BEND (BEND)

```
PROGRAM
DESCRIPTION:  THE MODEL FOR A SIEVE BEND (WEDGE WIRE) SCREEN
-----------   IS THAT OUTLINED BY LYNCH FOR A RANGE OF SLOT WIDTHS
              FROM 250-1000 MICROMETRES.  IT CONSISTS OF A SERIES OF
              EMPIRICAL EQUATIONS WHICH RELATE THE PARTITION CURVE
              PARAMETERS IN TERMS OF THE FEED SLURRY PERCENT SOLIDS,
              THE MASS FLOW RATE OF WATER, AND THE SLOT WIDTH
              (WIDTH OF OPENING BETWEEN THE BARS).


PROGRAMS AND SUBROUTINES REQUIRED:
---------------------------------

 XBEND,RDFILE,UDRIVR,BEND,BENOUT,PART

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

 NS     = NUMBER OF SIZE FRACTIONS
 NG     = NUMBER OF SPECIFIC GRAVITIES
 NC     = NUMBER OF CHARACTERISTICS
 SOL    = SRFD = SOLIDS FLOW RATE IN FEED(TONNES/HR)
 WAT    = WRFD = WATER FLOW RATE IN THE FEED(TONNES/HR)

 FEED   = 3 DIMENSIONAL ARRAY CONTAINING THE CHARACTERISTICS
          OF THE FEED

 PARAM  = PARAMETER VECTOR - 1 = SW
                             2 = EM
 SW     = SLOT WIDTH (MICROMETRES)
 EM     = SHARPNESS OF SEPARATION COEFFICENT

 OPT    = OPTION VECTOR (UNUSED)

 XMU    = SIZE VECTOR (MICROMETRES)


              DATA ENTRY FOR : BEND


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

6 1 1 4.5 10.5
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
56. 17. 7. 6.5 4.5 9.
 CHANGE?(Y/N)
n
```

```
 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
700. 2.9
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE OPTIONS  RELATED TO THIS SIMULATOR ARE:
0.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SIZES ARE:

4760. 2380. 1190. 595. 297. 149.
 CHANGE?(Y/N)
n

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

--------------------------------------------------------------------------------
                                 FEED STREAM
                                 SOLIDS FLOWRATE =   4.5
                                 WATER FLOWRATE  =  10.5
                                  ! ! ! ! ! !
                              !   ! ! ! ! ! !
                              !   ! ! ! ! ! !
                              !   ! ! ! ! ! !
                              !   V V V V V V
                              !
                               !
                                !
                                 !                   SLOT WIDTH =   700. MICRONS
                                  !
                                    !
                                      !
                                         !
                                            !==========>
                 UNDERSIZE PRODUCT                       OVERSIZE PRODUCT
                 SOLIDS FLOWRATE =    .4                 SOLIDS FLOWRATE =   4.1
                 WATER FLOWRATE  =   8.7                 WATER FLOWRATE  =   1.8

 TO CONTINUE ENTER ANY NUMBER AND CRO
```

SOLIDS DISTRIBUTION

SIZE RANGE	FEED WT. (%)	FEED ASH %	FINE WT. (%)	FINE ASH %	COARSE WT. (%)	COARSE ASH %
4760. - 2380.	56.00	0.00	0.00	0.00	62.01	0.00
2380. - 1190.	17.00	0.00	0.00	0.00	18.83	0.00
1190. - 595.	7.00	0.00	.00	0.00	7.75	0.00
595. - 297.	6.50	0.00	3.74	0.00	6.80	0.00
297. - 149.	4.50	0.00	20.89	0.00	2.74	0.00
149. - 0.	9.00	0.00	75.38	0.00	1.87	0.00
CUMULATIVE VALUES:	100.00	0.00	100.00	0.00	100.00	0.00

STOP
041700 MAXIMUM EXECUTION FL.
0.387 CP SECONDS EXECUTION TIME.

5.7 HCONE

In addition to verification of the source code this section is intended to provide guidance concerning calibration of the module parameters.

The data for the source code verification are found in reference (28). In their study, Stratton-Crawley and Agar implemented the Plitt hydrocyclone model to simulate a three-stage sandplant at INCO's Thompson mine. Only detailed data for the eight primary cyclones (Krebs D10LB-845) were presented.

The data were as follows:

- No. of cyclones CN: 8
- Cyclone diameter DC: 25.4 cm
- Vortex finder diameter DO: 8.9 cm
- Apex diameter DU: 3.17 cm
- Inlet diameter DI: 10.2 cm
- Free vortex height FVH: 78.7 cm.

The flow data were:

- Solids mass flow rate in feed SRFD: 316.5
- Water mass flow rate in feed WRFD: 799.4 tonnes/h
- Density of solids SG(1): 2.8 (assumed).

Calculated parameters:

- Per cent solids by volume in feed PHI: 12.39
- Volumetric flow rate (per cyclone) Q: 1901 L/min
- Feed slurry density: 1.223.

The following results were reported by Stratton-Crawley and Agar:

- D50C: 80 μm
- Volumetric fraction of solids in underflow: 0.4281
- Pressure drop P: 125 kPa
- Flow split S: 0.1547
- Sharpness of separation EM: 1.58

- Feed size analysis:

Interval top size (μm)	Weight per cent
297	4.9
212	11.7
150	14.1
106	13.0
75	9.4
53	6.2
45	40.7
	100.0

Pressure drop correlation using Equation 72

$$P = \frac{1.88 \times 1901^{1.78} \exp(0.0055 \times 12.39)}{25.4^{0.37}\ 10.2^{0.94}\ 78.7^{0.28}\ (3.17^2 + 8.9^2)^{0.87}} = 278.3 \text{ kPa}$$

(Observed 125 kPa)

set FPRESS = 0.449.

Volumetric flow split

$$\text{Head in metres} = \frac{125}{9.8 \times 1.223} = 10.43$$

Flow split calculated using Equation 69

$$S = \frac{1.9(3.17/8.19)^{3.31} 78.7^{0.54} (3.17^2 + 8.9^2)^{0.36} \exp(0.0054 \times 12.39)}{10.43^{0.24}\ 25.4^{1.11}}$$

= 0.0558 (observed 0.1547)

$$\text{FSPLT} = \frac{0.1547}{0.0558} = 2.76$$

set FSPLT = 2.76.

Cut size (d50c) using Equation 68

$$d50c = \frac{39.7\ 25.4^{0.46}\ 10.2^{0.6}\ 8.9^{1.21}\ \exp(0.063 \times 12.39)}{3.17^{0.71}\ 78.7^{0.38}\ 1901^{0.45}((2.8-1)/1.6)^{0.5}}$$

= 57.6 μm (measured 85 μm).

It is assumed that because of the relatively low DU/DO ratio and the fairly high per cent solids in the underflow, the higher observed d50c is due to the apex solids constraint. Thus FD50 will not be adjusted in the calibration. The FD50 should only be adjusted when the cyclone is operating with unconstrained discharge from the underflow.

Sharpness of separation using Equation 71

$$m = 1.94 \exp(-1.58 \frac{0.155}{1.155}) (\frac{25.4^2 \quad 78.7}{1901})^{0.15}$$

$$= 2.57 \text{ (measured 1.58)}$$

$$FEM = \frac{1.58}{2.57} = 0.615$$

set FEM = 0.615.

Apex solids constraint

Assuming that the cyclone was operating at constraining solids in the apex, the nominal constraint factor (i.e., at 20% feed solids) is calculated using Equation 73 as follows:

$$Lu20 = 0.428 + (20 - 12.39)0.002 = 0.443$$

Set ROPE = 0.443.

Entering all of these factors, the HCONE module produced the output which follows (using CYCOUT). Note the good agreement between the calculated and observed results. The d50c was not exact since it was increased to meet the underflow constraint.

It is of interest to compare the calibrated model with the results obtained by Stratton-Crawley and Agar as the apex is increased.

	Predicted		Measured	
Apex (cm)	d50c	m	d50c	m
3.17	89	1.58	80	1.58
3.81	50	1.37	59	1.37
4.44	45	1.15	39	1.13
5.08	41	0.97	28	1.0

Although the actual flow conditions were not reported and were therefore kept constant, it can be seen that the HCONE module alters both d50c and m with increasing apex size in a manner very close to that actually observed.

PLITT'S HYDROCYCLONE MODEL (HCONE)

PROGRAM DESCRIPTION: THE PLITT MODEL IS BASED ON A LARGE DATA BASE OF OVER 200 TESTS INVOLVING BOTH LABORATORY AND INDUSTRIAL SCALE CYCLONES. IT USES A PARTITION CURVE AND EMPIRICAL CORRELATIONS TO RELATE THE PARTITION CURVE PARAMETERS TO THE CYCLONE DIMENSIONS AND FEED CONDITIONS. THE EQUATIONS CONTAIN SCALING PARAMETERS THAT ALLOW FINE CALIBRATION TO FIT PARTICULAR EXPERIMENTAL DATA WITHOUT CHANGING THE MAIN COEFFICIENTS OF THE EQUATIONS.

THREE DIFFERENT MODULES OF HCONE CAN BE USED:

- HCONE1 - CALCULATES THE CYCLONE REDUCED EFFICIENCY CURVE FROM CYCLONE GEOMETRY AND OPERATING CONDITIONS
- HCONE2 - CALCULATES THE CYCLONE CORRECTED EFFICIENCY FROM GIVEN PARAMETERS D50C, EM AND RF AS DESIRED IN SECTION 2.2.7.1
- HCONE3 - READS DIRECTLY THE REAL EFFICIENCY CURVE

EACH OF THE THREE MODULES READS ITS OWN DATA FILE.

THE PROGRAMS AND SUBROUTINES ARE:

XHCONE,RDFILE,UDRIVR,HCONE1,HCONE2,HCONE3,CYCOUT,PART, 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 = SRFD = MASS FLOW RATE OF SOLIDS IN FEED (TONNES/HR)
WAT = WRFD = 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 SETS OF NS RECORDS EACH RECORD HAVING NG VALUES) (% WEIGHT)

FOR HCONE1

PARAM = PARAMETER VECTOR
- 1 = CN
- 2 = DU
- 3 = ROPE
- 4 = DC
- 5 = DO
- 6 = DI
- 7 = FD50
- 8 = FSPLT
- 9 = FPRESS
- 10 = FEM
- 11 = FVH

```
CN      = NUMBER OF CYCLONES IN PARALLEL
DU      = INSIDE DIAMETER OF UNDERFLOW ORIFICE OR
          SPIGOT (TYPICAL RANGE 0.3*DO TO 0.8*DO) (CM)
ROPE    = NOMINAL LIMITING FACTOR OF SOLIDS IN UNDERFLOW
          FOR A FEED OF 20% SOLIDS BY VOLUME
DC      = INSIDE DIAMETER OF CYCLONE AT THE  BOTTOM
          OF VORTEX FINDER (CM)
DO      = INSIDE DIAMETER  OF VORTEX FINDER OR OVERFLOW
          OUTLET (TYPICAL RANGE 0.15*DC TO 0.4*DC) (CM)
DI      = INLET DIAMETERS (OR AREA EQUIVALENT) AT POINT
          WHERE INLET ENTERS THE MAIN BODY OF CYCLONE (CM)
FD50    = ORE DEPENDENT CORRECTION FACTOR FOR D50
          CORRELATION (SET TO 1.0 WHEN NO CALIBRATION
          DATA ARE AVAILABLE)
FSPLT   = UNDERFLOW/OVERFLOW VOLUME SPLIT FACTOR (SET
          TO 1.0 FOR NORMAL OPERATION)
FPRESS  = PRESSURE DROP FACTOR (SET TO 1.0 FOR NORMAL
          OPERATION)
FEM     = SHARPNESS OF SEPARATION CALIBRATION FACTOR
          (SET TO 1.0 FOR NORMAL OPERATION)
FVH     = FREE VORTEX HEIGHT OR DISTANCE BETWEEN TOP
          OF APEX ORIFICE TO BOTTOM OF THE VORTEX
          FINDER (TYPICAL VALUES 2*DC TO 4*DC)

OPT     = OPTION VECTOR     - 1 = 1 (FOR HCONE1)

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


          DATA ENTRY FOR : HCONE1

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

7 1 1 316.5 799.37
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
4.9 11.7 14.1 13. 9.4 6.2 40.7
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
8. 3.175 .4433 25.4 8.9 10.2 1. 2.761 .4493 .615 78.7
 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:

297. 212. 150. 106. 75. 53. 45.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SPECIFIC GRAVITIES ARE:
2.8
 CHANGE?(Y/N)
n


                       OUTPUT FOR HCONE1

                       ALL MASS FLOWRATES IN TONNES/HOUR

                                       SOLIDS   171.1
                            --> OVERFLOW WATER   729.0
                           !             SLURRY  900.1
                    -------!-------
       SOLIDS  316.5     ! HYDROCYCLONE!
  FEED WATER   799.4 -->!             !
       SLURRY 1115.9     !  D50C=  85.0!          NO. OF UNITS  8
                         !     M= 1.580!
                         !    RF=  8.8%!          DU=   3.18 CM
                         \             /          DC=  25.40 CM
                          \           /           DO=   8.90 CM
                           \         /            DI=  10.20 CM
           PREDICTED        \       /            FVH=  78.70 CM
           PRESSURE          \     /
           DROP = 125.0 KPA   \   /
                               \ /
                                !          SOLIDS  145.4
                                V UNDERFLOW WATER    70.4
                                           SLURRY  215.8

  TO CONTINUE, ENTER ANY DIGIT AND <CR>0

              ***ROPE DISCHARGE IN UNDERFLOW - D50C INCREASED  1.5 TIMES
                 TO MEET UNDERFLOW % SOLIDS CONSTRAINT

...........................................................
```

PARTICLE SIZE ANALYSES OF FLOWSTREAMS

PARTICLE SIZE MICRONS	WEIGHT PERCENT FEED	UNDERFLOW	OVERFLOW
297 - 212	4.90	10.47	.16
212 - 150	11.70	23.11	2.00
150 - 106	14.10	23.07	6.48
106 - 75	13.00	16.22	10.26
75 - 53	9.40	8.47	10.19
53 - 45	6.20	4.29	7.82
45 - 0	40.70	14.37	63.07
	100.00	100.00	100.00

```
NO. OF SG FRACTIONS = 1
SOLIDS SG RANGED FROM  2.80 TO  2.80
...........................................................
```

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

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

              10     20     30     40     50     60     70     80     90    100
        ------+-------+-------+-------+-------+-------+-------+-------+-------+
   297. !                                                                     O
   212. !                                                             U   F  O
   150. !                                            U           F         O !
   106. !                            U                 F               O     !
    75. !                 U                   F                 O            !
    53. !           U                   F                O                   !
    45. !        U                 F               O                         !
        ------+-------+-------+-------+-------+-------+-------+-------+-------+
              10     20     30     40     50     60     70     80     90    100
   TO CONTINUE, ENTER ANY DIGIT AND <CR>0
        STOP
        036200 MAXIMUM EXECUTION FL.
         0.456 CP SECONDS EXECUTION TIME.

        FOR HCONE2:
        ----------

        PARAM   = PARAMETER VECTOR      - 1 = CN
                                          2 = DU
                                          3 = ROPE
                                          6 = RF
                                          7 = EM
                               8 TO (7+NG) = WORK5
        CN      = NUMBER OF CYCLONES IN PARALLEL
        DU      = INSIDE DIAMETER OF UNDERFLOW ORIFICE (CM)
        ROPE    = NOMINAL LIMITING FACTOR OF SOLIDS IN UNDERFLOW
                  FOR A FEED OF 20% SOLIDS BY VOLUME
        RF      = WATER RECOVERY TO THE UNDERFLOW (FRACTION)
        EM      = SHARPNESS OF SEPARATION COEFFICENT
        WORK5   = VECTOR OF D50C = CORRECTED EQUI-PARTITION
                  DIAMETERS

        OPT     = OPTION VECTOR        - 1 = 2 (FOR HCONE2)

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


                  DATA ENTRY FOR : HCONE2


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

   7 1 1 316.5 799.37
    CHANGE?(Y/N)
   n

    THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
   4.9 11.7 14.1 13. 9.4 6.2 40.7
    CHANGE?(Y/N)
   n
```

```
 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
8. 3.175 .4433 0. 0. .088 1.58 85.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE OPTIONS  RELATED TO THIS SIMULATOR ARE:
2.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SIZES ARE:

297. 212. 150. 106. 75. 53. 45.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SPECIFIC GRAVITIES ARE:
2.8
 CHANGE?(Y/N)
n

                       OUTPUT FOR HCONE2

                       ALL MASS FLOWRATES IN TONNES/HOUR

                                                 SOLIDS   171.1
                                 --> OVERFLOW WATER    729.0
                                 !               SLURRY   900.1
                          -------!-------
        SOLIDS   316.5    ! HYDROCYCLONE!
   FEED WATER    799.4 -->!             !
        SLURRY 1115.9     !  D50C=  85.0!            NO. OF UNITS  8
                          !     M= 1.580!
                          !    RF=  8.8%!            DU=    3.18 CM
                           \           /
                            \         /
                             \       /
                              \     /
                               \   /
                                \ /
                                 !             SOLIDS  145.4
                                 V UNDERFLOW WATER     70.3
                                               SLURRY  215.8

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

```
.............................................................
          PARTICLE SIZE ANALYSES OF FLOWSTREAMS
          -------------------------------------
```

PARTICLE SIZE MICRONS	WEIGHT PERCENT FEED	UNDERFLOW	OVERFLOW
297 - 212	4.90	10.47	.16
212 - 150	11.70	23.11	2.00
150 - 106	14.10	23.07	6.48
106 - 75	13.00	16.22	10.26
75 - 53	9.40	8.47	10.19
53 - 45	6.20	4.29	7.82
45 - 0	40.70	14.37	63.08
	100.00	100.00	100.00

```
         NO. OF SG FRACTIONS = 1
         SOLIDS SG RANGED FROM  2.80 TO  2.80
.............................................................
TO CONTINUE, ENTER ANY DIGIT AND <CR>0

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

          10     20     30     40     50     60     70     80     90    100
     ------+------+------+------+------+------+------+------+------+------+
297. !                                                                    O
212. !                                                             U   F  O
150. !                                            U           F         O !
106. !                            U                 F               O     !
 75. !                 U                   F                 O            !
 53. !           U                   F                O                   !
 45. !        U                 F               O                         !
     ------+------+------+------+------+------+------+------+------+------+
          10     20     30     40     50     60     70     80     90    100
TO CONTINUE, ENTER ANY DIGIT AND <CR>0
     STOP
     036200 MAXIMUM EXECUTION FL.
      0.391 CP SECONDS EXECUTION TIME.

     FOR HCONE3:
     ----------

     PARAM   = PARAMETER VECTOR     - 1 = CN
                                      2 = DU
                                      3 = ROPE
                                      4 = PJ
                                      5 = RF
                             6 TO (5+NS) = EFFICENCY CURVE VECTOR
     CN      = NUMBER OF CYCLONES IN PARALLEL
     DU      = INSIDE DIAMETER OF UNDERFLOW ORIFICE (CM)
     ROPE    = NOMINAL LIMITING FACTOR OF SOLIDS IN UNDERFLOW
               FOR A FEED OF 20% SOLIDS BY VOLUME
     RF      = WATER RECOVERY TO THE UNDERFLOW (FRACTION)
     PJ      = % SOLIDS BY VOLUME IN UNDERFLOW

     OPT     = OPTION VECTOR          - 1 = 3 (FOR HCONE3)

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

```
                DATA ENTRY FOR : HCONE3

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

7 1 1 316.5 799.37
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
4.9 11.7 14.1 13. 9.4 6.2 40.7
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
8. 3.175 .4433 0. .088 .98188 .90737 .75705 .57554 .41404 .31765
.16217
 CHANGE?(Y/N)
n

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

 THE DEFAULT VALUES FOR THE ARRAY OF SIZES ARE:

297. 212. 150. 106. 75. 53. 45.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SPECIFIC GRAVITIES ARE:
2.8
 CHANGE?(Y/N)
n
```

```
                OUTPUT FOR HCONE3

                ALL MASS FLOWRATES IN TONNES/HOUR

                                          SOLIDS  170.8
                            --> OVERFLOW WATER    729.0
                           !              SLURRY  899.8
                    -------!-------
     SOLIDS  316.5  ! HYDROCYCLONE!
FEED WATER   799.4 -->!            !
     SLURRY 1115.9  !              !          NO. OF UNITS  8
                    !              !
                    !    RF=  8.8%!           DU=    3.18 CM
                     \            /
                      \          /
                       \        /
                        \      /
                         \    /
                          \  /
                           \ /
                           !           SOLIDS  145.7
                           V UNDERFLOW WATER    70.3
                                       SLURRY  216.1
```

TO CONTINUE, ENTER ANY DIGIT AND <CR>0

....

PARTICLE SIZE ANALYSES OF FLOWSTREAMS

PARTICLE SIZE MICRONS	WEIGHT PERCENT FEED	UNDERFLOW	OVERFLOW
297 - 212	4.90	10.45	.16
212 - 150	11.70	23.06	2.01
150 - 106	14.10	23.18	6.35
106 - 75	13.00	16.25	10.23
75 - 53	9.40	8.45	10.21
53 - 45	6.20	4.28	7.84
45 - 0	40.70	14.33	63.20
	100.00	100.00	100.00

NO. OF SG FRACTIONS = 1
SOLIDS SG RANGED FROM 2.80 TO 2.80

....

TO CONTINUE, ENTER ANY DIGIT AND <CR>0

CUMULATIVE WEIGHT % VS PASSING SIEVE APERTURE

```
            10     20     30     40     50     60     70     80     90    100
      ------+------+------+------+------+------+------+------+------+------+
 297. !                                                                    O
 212. !                                                             U   F  O
 150. !                                            U           F         O !
 106. !                            U                 F               O     !
  75. !                 U                   F                 O            !
  53. !           U                   F                O                   !
  45. !        U                 F               O                         !
      ------+------+------+------+------+------+------+------+------+------+
            10     20     30     40     50     60     70     80     90    100
```

TO CONTINUE, ENTER ANY DIGIT AND <CR>0

5.8 GCLASS

The data for the source code verification is the sample calculation presented by Roberts and Fitch (9). The given data are:

– Feed size analysis:

Interval top size (µm)	Weight per cent
833	13.7
589	10.3
417	18.3
295	14.2
147	6.1
104	4.6
74	22.1
	100.1

d50c = 214 µm (calculated from size analyses)

m = 2.08 (best fit value)

% solids by volume in sands = 51.78

Feed solids mass flow rate = 100 tonnes/h (assumed)

Feed water including dilution = 92.3 tonnes/h

Specific gravity solids = 2.65

% solids by volume in feed = 29.0

% solids by volume in overflow = 14.435

Overflow slurry specific gravity = 1.255

Specific gravity of feed = 1.479

Effective specific gravity = 1.367 (ave. feed and overflow)

Volume split, S = 0.595

Volumetric flow rate to overflow = (100/2.65 + 92.3) (1 – 1.595) = 81.52 m^3/h

Effective % solids by volume = 22.2 (ave. feed and overflow)

Effective viscosity = 1.91/(1.0 – 1.45*0.222)**1.83 = 3.89 cp

Settling velocity of d50c particle using Equation 74

$$v = \frac{4/3 \times 980 \times 0.0212^2\,(2.65 - 1.367)}{1.038\,(2 \times 0.0212^{1.5}\sqrt{\frac{980 \times 2.65 \times 1.367}{3}} + \sqrt{48 \times 3.01 \times 0.0389}}$$

$= 0.7091$ cm/sec (25.53 m/h)

Required area = 81.52/25.53 = 3.19 m^2.

Using these values, the GCLASS module calculated the output which follows. It can be seen from the following sample run that the d50c value is very close to that used for the calculation. The solids split and the size analyses of the overflow and underflow are very close to that calculated by Roberts and Fitch, e.g., solids recovery to coarse product is 65.7% compared with Fitch's values of 66.5%.

SIMULATION OF GRAVITY CLASSIFICATION (GCLASS)

PROGRAM DESCRIPTION: PLITT AND FLINTOFF HAVE COMBINED THE FUNDAMENTAL STUDIES OF GRAVITY CLASSIFIERS BY SCHUBERT AND NESSE WITH THE BASIC DESIGN PROCEDURES BY ROBERTS AND FITCH TO FORMULATE THIS MODEL. IT USES THE SETTLING POOL AREA, THE COARSE SOLIDS REMOVAL CAPACITY AND THE SOLIDS CONTENT IN THE COARSE SOLIDS STREAM ALONG WITH THE CHARCTERISTICS OF THE FEED STREAM. THE MODEL IS APPLICABLE TO ANY TYPE OF GRAVITY CLASSIFIER WHERE THE SETTLING AREA CAN BE DEFINED, E.Q. HYDROSEPARATORS, SPIRAL OR RAKE CLASSIFIERS, CLASSIFIER CONES.

THE PROGRAMS AND SUBROUTINES ARE:

XGCLASS,RDFILE,UDRIVR,GCLASS,PART,GCLOUT

THE DATA REQUIRED IS AS FOLLOWS:

```
NS     = NUMBER OF SIZE INTERVALS
NG     = NUMBER OF SPECIFIC GRAVITY FRACTIONS
NC     = NUMBER OF CHARACTERISTICS (WEIGHT, ASSAYS, ETC.)
SOL    = SRFD = SOLIDS MASS FLOWRATE IN THE FEED (TONNES/HR)
WAT    = WRFD = WATER MASS FLOWRATE IN THE FEED (TONNES/HR)
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)
         (% WEIGHT)

PARAM  = PARAMETER VECTOR - 1 = DILWAT
                            2 = AREA
                            3 = EM
                            4 = CSCAP
                            5 = PSVCS
DILWAT = MASS FLOW RATE OF DILUTION WATER ADDED TO
         CLASSIFIER (TONNES/HR)
AREA   = EFFECTIVE OVERFLOW POOL AREA(SQUARE METER)
EM     = SHARPNESS OF SEPARATION COEFFICIENT
CSCAP  = COARSE SOLID REMOVAL CAPACITY (SOLIDS
         RAKING CAPACITY)
PSVCS  = PERCENT SOLIDS BY VOLUME IN COARSE PRODUCTS

OPT    = OPTION VECTOR (UNUSED)

XMU    = VECTOR OF PASSING SIZES FROM COARSE TO FINE
         (MICROMETRES)
SG     = VECTOR OF UPPER BOUNDS OF SPECIFIC GRAVITY
         INTERVALS
```

```
                DATA ENTRY FOR : GCLASS

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

8 1 1 100. 92.3
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
13.7 10.3 18.3 14.2 10.7 6.1 4.6 22.1
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
0. 3.19 2.08 300. 51.78
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE OPTIONS  RELATED TO THIS SIMULATOR ARE:
0.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SIZES ARE:

833. 589. 417. 295. 208. 147. 104. 74.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SPECIFIC GRAVITIES ARE:
2.65
 CHANGE?(Y/N)
n
```

GRAVITY CLASSIFIER OUTPUT (GCLASS)

ALL MASS FLOWRATES IN TONNES/HR

```
                       FEED
                        ! SOLIDS 100.0
                        ! WATER    92.3 + DILUTION   0.0
                        ! SLURRY 192.3
                        !                        !
                        !                    !   !
                        !                !   !   !
                        !            !   !   !   !
                        !        !   !   !   !   !   SANDS
                        V    !   !   !   !   !   !   ---->
                         !   !   !   !   !   !        SOLIDS  65.9
   OVERFLOW          !   !   !   !   !   !         *  WATER   23.1
     <----------     !   !   !   !   !         *      SLURRY  89.0
    SOLIDS  34.1*    !   !   !   !         *
    WATER   69.2     !   !   !         *
    SLURRY 103.3 *   !   !         *
                     !         *
                  *        *          D50C= 214.2 MICRONS
                       *                 M=  2.08
                   *                    RF= 25.06 %
                                      AREA=   3.2 SQ. M
```

TO CONTINUE ENTER ANY NUMBER AND CRO

....

PARTICLE SIZE ANALYSES OF FLOWSTREAMS

PARTICLE SIZE MICRONS	WEIGHT PERCENT FEED	SANDS	OVERFLOW
833 - 589	13.70	20.79	.01
589 - 417	10.30	15.44	.38
417 - 295	18.30	24.94	5.48
295 - 208	14.20	15.33	12.02
208 - 147	10.70	8.63	14.70
147 - 104	6.10	3.73	10.67
104 - 74	4.60	2.30	9.04
74 - 0	22.10	8.85	47.70
	100.00	100.00	100.00

NO. OF SG FRACTIONS = 1

SOLIDS SG RANGED FROM 2.65 TO 2.65

....

STOP

034500 MAXIMUM EXECUTION FL.

0.405 CP SECONDS EXECUTION TIME.

5.9 SGSEP

The data used to validate the SPOC module were taken from a sample calculation for a concentration table in the Battelle (2) documentation. The results shown on the first SGSEP sample run are different from those obtained in the Battelle calculations. The reason for the discrepancy is that the Battelle module does not iteratively solve the model, but makes only a single *pass*. Relaxing the convergence criterion in SGSEP to the extent that it would emulate the Battelle module gave essentially the same results. In this case the only difference arose from an improper computation of probable error by the Battelle output routine.

Two additional runs were made using composite size data from the same data set. In the first, a single size interval feed stream was used to reflect a minimum of feed stream information. The results are included for comparison with the more detailed run above. The second run used a single partition curve (taken as +1/2" material in Table 8). The user must be careful to ensure that, when using a single partition curve, the single entry in the reference size vector must be greater than or equal to the top size in the feed stream. Once again the results are presented for the reader's perusal.

SIMULATION OF A SPECIFIC GRAVITY SEPARATOR (SGSEP)

PROGRAM DESCRIPTION: THIS MODEL IS THE PARTITION CURVE USED IN THE COAL INDUSTRY FOR MANY YEARS. THIS CURVE IS, IN GENERAL, CONSIDERED TO BE CHARACTERISTIC OF THE UNIT USED AND INDEPENDENT OF THE FEED DENSITY. IT IS DEPENDENT ON THE TYPE OF MEDIUM, THE SIZE COMPOSITION OF THE FEED AND THE FEED RATE. IT USES DATA PUBLISHED BY USBM FOR:

1) DENSE MEDIUM VESSEL/BATH,
2) DENSE MEDIUM CYCLONE,
3) MINERAL JIG,
4) CONCENTRATING TABLE AND
5) COMPOUND WATER CYCLONE OR HYDROCYCLONE.

FROM THESE DATA, GOTTFRIED AND BATTELLE LABORATORIES CONSTRUCTED SIMULATION MODULES INCORPORATING THIS PARTITION CURVE INFORMATION AS A DEFAULT DATA BASE. IT WAS FOUND THAT BY USING THESE GENERALIZED CURVES FOR A PARTICULAR UNIT, ONLY THE SPECIFIC GRAVITY OF SEPARATION NEED BE SPECIFIED.

PARTION CURVE DATA : TO TEST THIS MODEL, PARTITION CURVE DATA FOR A CONCENTRATING TABLE (IN THE ABOVE REFERENCE) RESIDE ON A SEPARATE DISK FILE. THESE CONSIST OF:

- NSREF = NUMBER OF SIZE INTERVALS ASSOCIATED WITH THE REFERENCE PARTITION DATA
- NGREF = NUMBER OF GRAVITY RATIO DATA POINTS ON ANY REFERENCE PARTITION CURVE
- XMUREF = VECTOR OF UPPER SIZES FOR THE SIZE INTERVALS ASSOCIATED WITH THE REFERENCE PARTITION DATA (MICROMETRES)
- RATIO = A 2-DIMENSIONAL ARRAY CONTAINING THE ABCISSA (GRAVITY RATIO) DATA FOR THE REFERENCE PARTITION CURVES
- PART = A 2-DIMENSIONAL ARRAY CONTAINING THE ORDINATE (DISTRIBUTION FACTORS) DATA CORRESPONDING TO THE RATIO DATA

THE PROGRAMS AND SUBROUTINES USED ARE:

XSGSEP,RDFILE,UDRIVR,SGSEP,SGSOUT,LAGRAN,DETOUT,SGDOUT

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 (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 SETS
                  OF NS RECORDS EACH RECORD HAVING NG VALUES)
                 (% WEIGHT)

      PARAM    = PARAMETER VECTOR    - 1 = SGSP
                                       2 = WATOF
      SGSP     = SPECIFIC GRAVITY OF SEPARATION
      WATOF    = PERCENT MOISTURE IN THE CLEAN COAL PRODUCT

      OPT      = OPTION VECTOR       - 1 = FLAG
                                       2 = TYPE
      FLAG     = FLAG REQUESTING OUTPUT OF DETAILED EQUIPMENT
                 AND STREAM CHARACTERISTICS
               = 0:  SUMMARY OUTPUT
               = 1:  SUMMARY PLUS DETAILED OUTPUT
      TYPE     = SPECIFIES THE PARTICULAR SEPARATION DEVICE
               = 1:  DENSE MEDIUM VESSEL
               = 2:  DENSE MEDIUM CYCLONE
               = 3:  JIG
               = 4:  CONCENTRATING TABLE
               = 5:  AUTOMEDIUM CYCLONE

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


                 DATA ENTRY FOR : SGSEP


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

4 8 3 169.7 0.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
11.18 .741 1.051 1.724 3.619 3.13 9.698 13.766
16.682 .849 1.519 1.735 1.969 1.252 4.044 8.55
4.06 .21 .379 .47 .598 .684 1.296 4.601
1.373 .066 .122 .19 .34 .732 1.195 2.183
75.45 42.03 33.65 25.82 15.75 9.58 4.75 2.47
76.51 42.66 33.14 25.58 15.57 9.05 4.44 1.95
73.45 41.32 32.39 24.97 15.56 8.52 5.61 1.86
69.53 38.94 29.89 21.53 12.56 4.86 3.21 1.43
2373. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
2250. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
2271. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
2145. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
1.58 0.
 CHANGE?(Y/N)
n
```

```
 THE DEFAULT VALUES OF THE OPTIONS  RELATED TO THIS SIMULATOR ARE:
1. 4.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SIZES ARE:

25400. 6350. 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 S.G. SEPARATOR (SGSEP)

```
--------------------------------------------------------------------------------


                                  -------------------------
                                  !                       !
                                  !    WATOF =    0.0     !
FEED STREAM                  ====>!    SGSP= 1.580        !====>FLOAT STREAM
SOLIDS FLOWRATE= 169.7====>!       TABLE                  !====>SOLIDS FLOWRATE= 104.4
WATER FLOWRATE =    0.0====>!                             !====>WATER FLOWRATE =    0.0
                                  !                       !
                                  !                       !
                                  -------------------------
                                        ! ! ! ! ! ! ! ! ! !
                                        ! ! ! ! ! ! ! ! ! !
                                        ! ! ! ! ! ! ! ! ! !
                                        V V V V V V V V V V
                                         REJECT STREAM
                                         SOLIDS FLOWRATE=  65.3
                                         WATER FLOWRATE =   0.0
```

SOLIDS DISTRIBUTION

S.G. RANGE	FEED WT. (%)	FEED ASH %	REJECT WT. (%)	REJECT ASH %	COAL WT. (%)	COAL ASH %
2.600 - 1.800	33.30	75.49	84.21	75.59	1.48	72.17
1.800 - 1.700	1.87	42.13	4.29	42.25	.35	41.20
1.700 - 1.600	3.07	33.09	5.68	33.27	1.44	32.67
1.600 - 1.500	4.12	25.42	4.04	25.61	4.17	25.31
1.500 - 1.400	6.53	15.51	1.20	15.58	9.85	15.51
1.400 - 1.350	5.80	8.74	.23	8.39	9.27	8.75
1.350 - 1.300	16.23	4.63	.20	4.87	26.25	4.63
1.300 - 1.250	29.10	2.14	.16	1.81	47.18	2.14
CUMULATIVE VALUES:	100.01	30.88	100.02	68.59	100.00	7.30

CUMULATIVE CHARACTERISTIC VALUES(NC>2)

CHAR.# 2   FEED=10192.87 REJECT= 3523.69 COAL=14360.88

STATISTICAL SUMMARY OF UNIT OPERATING EFFICIENCY

SIZE INTERVAL	S.G. SEPAR.	PROBABLE ERROR	IMPERF. RATIO	ERROR AREA	ACTUAL YIELD	THEOR. YIELD	NEAR GRAVITY
1	1.564	.057	.101	40.47	69.64	70.62	7.67
2	1.569	.060	.105	54.96	47.00	48.94	9.26
3	1.689	.207	.300	123.02	63.98	68.00	5.04
4	2.029	.209	.203	172.36	83.83	86.22	5.54
COMPOSITE	1.580	.082	.142	66.49	61.54	64.08	7.62

CLEAN COAL SOLIDS STREAM

				DIRECT VALUES		
SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
25400.	- 1.300	22.37	2.47	15355.00		
X 6350.	- 1.350	15.73	4.75	14907.00		
50.82%	- 1.400	5.05	9.58	13909.00		
	- 1.500	5.56	15.75	12682.00		
	- 1.600	1.67	25.82	11077.00		
	- 1.700	.30	33.65	9723.00		
	- 1.800	.03	42.03	8269.00		
	- 2.600	.10	75.45	2373.00		
6350.	- 1.300	13.88	1.95	15355.00		
X 595.	- 1.350	6.55	4.44	14907.00		
27.95%	- 1.400	2.00	9.05	13909.00		
	- 1.500	2.91	15.57	12682.00		
	- 1.600	1.65	25.58	11077.00		
	- 1.700	.61	33.14	9723.00		
	- 1.800	.10	42.66	8269.00		
	- 2.600	.25	76.51	2250.00		
595.	- 1.300	7.41	1.86	15355.00		
X 149.	- 1.350	2.05	5.61	14907.00		
12.78%	- 1.400	1.04	8.52	13909.00		
	- 1.500	.84	15.56	12682.00		
	- 1.600	.56	24.97	11077.00		
	- 1.700	.35	32.39	9723.00		
	- 1.800	.14	41.32	8269.00		
	- 2.600	.40	73.45	2271.00		

149.	- 1.300	3.53	1.43	15355.00
X 0.	- 1.350	1.92	3.21	14907.00
8.45%	- 1.400	1.17	4.86	13909.00
	- 1.500	.54	12.56	12682.00
	- 1.600	.29	21.53	11077.00
	- 1.700	.18	29.89	9723.00
	- 1.800	.08	38.94	8269.00
	- 2.600	.73	69.53	2145.00

CUMULATIVE VALUES

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
25400.	- 1.300	44.02	2.47	15355.00		
X 6350.	- 1.350	74.97	3.41	15170.04		
50.82%	- 1.400	84.91	4.13	15022.33		
	- 1.500	95.86	5.46	14755.16		
	- 1.600	99.15	6.14	14633.14		
	- 1.700	99.75	6.30	14603.62		
	- 1.800	99.80	6.32	14600.20		
	- 2.600	100.00	6.46	14575.65		
6350.	- 1.300	49.64	1.95	15355.00		
X 595.	- 1.350	73.07	2.75	15211.35		
27.95%	- 1.400	80.24	3.31	15094.98		
	- 1.500	90.65	4.72	14817.92		
	- 1.600	96.54	5.99	14589.59		
	- 1.700	98.73	6.59	14481.88		
	- 1.800	99.10	6.73	14458.69		
	- 2.600	100.00	7.36	14348.47		
595.	- 1.300	57.95	1.86	15355.00		
X 149.	- 1.350	73.96	2.67	15257.98		
12.78%	- 1.400	82.14	3.25	15123.74		
	- 1.500	88.74	4.17	14942.11		
	- 1.600	93.09	5.14	14761.36		
	- 1.700	95.83	5.92	14617.31		
	- 1.800	96.91	6.31	14546.86		
	- 2.600	100.00	8.39	14167.14		
149.	- 1.300	41.80	1.43	15355.00		
X 0.	- 1.350	64.58	2.06	15197.00		
8.45%	- 1.400	78.44	2.55	14969.39		
	- 1.500	84.80	3.30	14797.82		
	- 1.600	88.25	4.02	14652.15		
	- 1.700	90.36	4.62	14537.43		
	- 1.800	91.35	4.99	14469.29		
	- 2.600	100.00	10.58	13403.11		

REJECT COAL SOLIDS STREAM

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	DIRECT VALUES CHAR. #2	CHAR. #3	CHAR. #4
25400.	- 1.300	.00	2.47	15355.00		
X 6350.	- 1.350	.05	4.75	14907.00		
35.45%	- 1.400	.05	9.58	13909.00		
	- 1.500	.51	15.75	12682.00		
	- 1.600	1.81	25.82	11077.00		
	- 1.700	2.25	33.65	9723.00		
	- 1.800	1.88	42.03	8269.00		
	- 2.600	28.91	75.45	2373.00		
6350.	- 1.300	.03	1.95	15355.00		
X 595.	- 1.350	.03	4.44	14907.00		
50.44%	- 1.400	.05	9.05	13909.00		
	- 1.500	.46	15.57	12682.00		
	- 1.600	1.88	25.58	11077.00		
	- 1.700	2.97	33.14	9723.00		
	- 1.800	2.04	42.66	8269.00		
	- 2.600	42.98	76.51	2250.00		
595.	- 1.300	.11	1.86	15355.00		
X 149.	- 1.350	.09	5.61	14907.00		
11.52%	- 1.400	.11	8.52	13909.00		
	- 1.500	.20	15.56	12682.00		
	- 1.600	.33	24.97	11077.00		
	- 1.700	.42	32.39	9723.00		
	- 1.800	.33	41.32	8269.00		
	- 2.600	9.92	73.45	2271.00		
149.	- 1.300	.03	1.43	15355.00		
X 0.	- 1.350	.03	3.21	14907.00		
2.61%	- 1.400	.03	4.86	13909.00		
	- 1.500	.02	12.56	12682.00		
	- 1.600	.03	21.53	11077.00		
	- 1.700	.03	29.89	9723.00		
	- 1.800	.04	38.94	8269.00		
	- 2.600	2.40	69.53	2145.00		

		CUMULATIVE VALUES				
SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
25400.	- 1.300	.00	2.47	15355.00		
X 6350.	- 1.350	.13	4.75	14907.00		
35.45%	- 1.400	.27	7.24	14392.99		
	- 1.500	1.72	14.39	12955.33		
	- 1.600	6.82	22.94	11550.06		
	- 1.700	13.15	28.10	10670.10		
	- 1.800	18.46	32.11	9979.32		
	- 2.600	100.00	67.45	3777.19		
6350.	- 1.300	.05	1.95	15355.00		
X 595.	- 1.350	.12	3.36	15101.07		
50.44%	- 1.400	.21	5.90	14568.78		
	- 1.500	1.13	13.74	13039.31		
	- 1.600	4.85	22.81	11535.60		
	- 1.700	10.75	28.48	10541.55		
	- 1.800	14.80	32.36	9919.61		
	- 2.600	100.00	69.98	3384.73		
595.	- 1.300	.94	1.86	15355.00		
X 149.	- 1.350	1.75	3.59	15148.39		
11.52%	- 1.400	2.68	5.29	14720.97		
	- 1.500	4.45	9.39	13907.61		
	- 1.600	7.33	15.51	12796.14		
	- 1.700	11.02	21.16	11767.17		
	- 1.800	13.85	25.28	11052.18		
	- 2.600	100.00	66.78	3487.03		
149.	- 1.300	1.00	1.43	15355.00		
X 0.	- 1.350	2.10	2.37	15118.96		
2.61%	- 1.400	3.24	3.24	14693.51		
	- 1.500	4.18	5.32	14244.33		
	- 1.600	5.21	8.55	13614.51		
	- 1.700	6.48	12.71	12854.77		
	- 1.800	7.91	17.47	12023.70		
	- 2.600	100.00	65.41	2926.81		

STOP
041000 MAXIMUM EXECUTION FL.
1.393 CP SECONDS EXECUTION TIME.

```
               DATA ENTRY FOR : SGSEP(CONSOL)

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

1 8 3 169.7 0.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
33.295 1.866 3.071 4.119 6.526 5.798 16.233 29.1
75.49 42.13 33.09 25.42 15.51 8.74 4.63 2.14
2289. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
1.58 0.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE OPTIONS  RELATED TO THIS SIMULATOR ARE:
1. 4.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SIZES ARE:

12700.
 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 S.G. SEPARATOR (SGSEP)

```
                                   -------------------------
                                   !                       !
                                   !    WATOF =    0.0     !
FEED STREAM                   ====>!    SGSP= 1.580        !====>FLOAT STREAM
SOLIDS FLOWRATE= 169.7====>!        TABLE                  !====>SOLIDS FLOWRATE= 103.7
WATER FLOWRATE =     0.0====>!                             !====>WATER FLOWRATE =   0.0
                                   !                       !
                                   !                       !
                                   -------------------------
                                         ! ! ! ! ! ! ! ! ! !
                                         ! ! ! ! ! ! ! ! ! !
                                         ! ! ! ! ! ! ! ! ! !
                                         V V V V V V V V V V
                                          REJECT STREAM
                                          SOLIDS FLOWRATE=  66.0
                                          WATER FLOWRATE =   0.0
```

SOLIDS DISTRIBUTION

S.G. RANGE	FEED WT. (%)	FEED ASH %	REJECT WT. (%)	REJECT ASH %	COAL WT. (%)	COAL ASH %
2.600 - 1.800	33.30	75.49	84.46	75.49	.74	75.49
1.800 - 1.700	1.87	42.13	4.45	42.13	.22	42.13
1.700 - 1.600	3.07	33.09	5.80	33.09	1.33	33.09
1.600 - 1.500	4.12	25.42	3.92	25.42	4.25	25.42
1.500 - 1.400	6.53	15.51	1.07	15.51	10.00	15.51
1.400 - 1.350	5.80	8.74	.15	8.74	9.39	8.74
1.350 - 1.300	16.23	4.63	.11	4.63	26.49	4.63
1.300 - 1.250	29.10	2.14	.06	2.14	47.58	2.14
CUMULATIVE VALUES:	100.01	30.87	100.02	68.72	100.00	6.79

CUMULATIVE CHARACTERISTIC VALUES(NC>2)

CHAR.# 2 FEED=10192.69 REJECT= 3481.11 COAL=14464.13

STATISTICAL SUMMARY OF UNIT OPERATING EFFICIENCY

SIZE INTERVAL	S.G. SEPAR.	PROBABLE ERROR	IMPERF. RATIO	ERROR AREA	ACTUAL YIELD	THEOR. YIELD	NEAR GRAVITY
COMPOSITE	1.580	.073	.127	54.33	61.11	62.84	7.61

CLEAN COAL SOLIDS STREAM

DIRECT VALUES

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
12700.	- 1.300	47.58	2.14	15355.00		
X 0.	- 1.350	26.49	4.63	14907.00		
100.00%	- 1.400	9.39	8.74	13909.00		
	- 1.500	10.00	15.51	12682.00		
	- 1.600	4.25	25.42	11077.00		
	- 1.700	1.33	33.09	9723.00		
	- 1.800	.22	42.13	8269.00		
	- 2.600	.74	75.49	2289.00		

CUMULATIVE VALUES

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
12700.	- 1.300	47.58	2.14	15355.00		
X 0.	- 1.350	74.07	3.03	15194.78		
100.00%	- 1.400	83.46	3.67	15050.11		
	- 1.500	93.46	4.94	14796.75		
	- 1.600	97.71	5.83	14635.00		
	- 1.700	99.04	6.20	14568.92		
	- 1.800	99.26	6.28	14554.70		
	- 2.600	100.00	6.79	14464.13		

REJECT COAL SOLIDS STREAM

DIRECT VALUES

SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
12700.	- 1.300	.06	2.14	15355.00		
X 0.	- 1.350	.11	4.63	14907.00		
100.02%	- 1.400	.15	8.74	13909.00		
	- 1.500	1.07	15.51	12682.00		
	- 1.600	3.92	25.42	11077.00		
	- 1.700	5.80	33.09	9723.00		
	- 1.800	4.45	42.13	8269.00		
	- 2.600	84.46	75.49	2289.00		

```
                              CUMULATIVE VALUES
  SIZE      SPEC.        WT.      ASH        CHAR.      CHAR.      CHAR.
INTERVAL    GRAV.         %        %          #2         #3         #4
--------------------------------------------------------------------------------
  12700.   - 1.300       .06     2.14   15355.00
X     0.   - 1.350       .17     3.77   15060.84
100.02%    - 1.400       .33     6.10   14522.15
           - 1.500      1.39    13.31   13112.72
           - 1.600      5.31    22.24   11611.69
           - 1.700     11.11    27.91   10625.40
           - 1.800     15.56    31.97    9952.05
           - 2.600    100.00    68.72    3481.11
--------------------------------------------------------------------------------
     STOP
     041000 MAXIMUM EXECUTION FL.
      0.881 CP SECONDS EXECUTION TIME.

              DATA ENTRY FOR : SGSEP(CONSOL)

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

1 8 3 169.7 0.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE FEED DISTRIBUTION ARE:
33.295 1.866 3.071 4.119 6.526 5.798 16.233 29.1
75.49 42.13 33.09 25.42 15.51 8.74 4.63 2.14
2289. 8269. 9723. 11077. 12682. 13909. 14907. 15355.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE PARAMETERS  RELATED TO THIS SIMULATOR ARE:
1.58 0.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES OF THE OPTIONS  RELATED TO THIS SIMULATOR ARE:
1. 4.
 CHANGE?(Y/N)
n

 THE DEFAULT VALUES FOR THE ARRAY OF SIZES ARE:

12700.
 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 S.G. SEPARATOR (SGSEP)

```
                                  -------------------------
                                  !                       !
                                  !    WATOF =    0.0     !
FEED STREAM                 ====>!    SGSP= 1.580        !====>FLOAT STREAM
SOLIDS FLOWRATE= 169.7====>!    TABLE                  !====>SOLIDS FLOWRATE= 103.5
WATER FLOWRATE =    0.0====>!                           !====>WATER FLOWRATE =    0.0
                                  !                       !
                                  !                       !
                                  -------------------------
                                        ! ! ! ! ! ! ! ! ! !
                                        ! ! ! ! ! ! ! ! ! !
                                        ! ! ! ! ! ! ! ! ! !
                                        V V V V V V V V V V
                                         REJECT STREAM
                                         SOLIDS FLOWRATE=  66.2
                                         WATER FLOWRATE =   0.0
```

SOLIDS DISTRIBUTION

S.G. RANGE	FEED WT. (%)	FEED ASH %	REJECT WT. (%)	REJECT ASH %	COAL WT. (%)	COAL ASH %
2.600 - 1.800	33.30	75.49	84.78	75.49	.34	75.49
1.800 - 1.700	1.87	42.13	4.66	42.13	.08	42.13
1.700 - 1.600	3.07	33.09	6.03	33.09	1.17	33.09
1.600 - 1.500	4.12	25.42	3.75	25.42	4.36	25.42
1.500 - 1.400	6.53	15.51	.68	15.51	10.27	15.51
1.400 - 1.350	5.80	8.74	.08	8.74	9.46	8.74
1.350 - 1.300	16.23	4.63	.04	4.63	26.60	4.63
1.300 - 1.250	29.10	2.14	.00	2.14	47.73	2.14
CUMULATIVE VALUES:	100.01	30.87	100.02	69.01	100.00	6.46

CUMULATIVE CHARACTERISTIC VALUES(NC>2)

CHAR.# 2 FEED=10192.69 REJECT= 3430.09 COAL=14522.36

STATISTICAL SUMMARY OF UNIT OPERATING EFFICIENCY

SIZE INTERVAL	S.G. SEPAR.	PROBABLE ERROR	IMPERF. RATIO	ERROR AREA	ACTUAL YIELD	THEOR. YIELD	NEAR GRAVITY
COMPOSITE	1.580	.064	.110	42.00	60.97	61.98	7.61

CLEAN COAL SOLIDS STREAM

				DIRECT VALUES		
SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
12700.	- 1.300	47.73	2.14	15355.00		
X 0.	- 1.350	26.60	4.63	14907.00		
100.00%	- 1.400	9.46	8.74	13909.00		
	- 1.500	10.27	15.51	12682.00		
	- 1.600	4.36	25.42	11077.00		
	- 1.700	1.17	33.09	9723.00		
	- 1.800	.08	42.13	8269.00		
	- 2.600	.34	75.49	2289.00		

				CUMULATIVE VALUES		
SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
12700.	- 1.300	47.73	2.14	15355.00		
X 0.	- 1.350	74.32	3.03	15194.68		
100.00%	- 1.400	83.78	3.68	15049.52		
	- 1.500	94.05	4.97	14791.01		
	- 1.600	98.41	5.87	14626.56		
	- 1.700	99.59	6.19	14568.73		
	- 1.800	99.66	6.22	14563.97		
	- 2.600	100.00	6.46	14522.36		

REJECT COAL SOLIDS STREAM

				DIRECT VALUES		
SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
12700.	- 1.300	.00	2.14	15355.00		
X 0.	- 1.350	.04	4.63	14907.00		
100.02%	- 1.400	.08	8.74	13909.00		
	- 1.500	.68	15.51	12682.00		
	- 1.600	3.75	25.42	11077.00		
	- 1.700	6.03	33.09	9723.00		
	- 1.800	4.66	42.13	8269.00		
	- 2.600	84.78	75.49	2289.00		

CUMULATIVE VALUES						
SIZE INTERVAL	SPEC. GRAV.	WT. %	ASH %	CHAR. #2	CHAR. #3	CHAR. #4
12700.	- 1.300	.00	2.14	15355.00		
X 0.	- 1.350	.04	4.63	14907.00		
100.02%	- 1.400	.12	7.31	14255.44		
	- 1.500	.80	14.28	12917.87		
	- 1.600	4.54	23.47	11399.73		
	- 1.700	10.57	28.96	10443.16		
	- 1.800	15.24	32.99	9777.85		
	- 2.600	100.00	69.01	3430.09		

STOP
041000 MAXIMUM EXECUTION FL.
0.716 CP SECONDS EXECUTION TIME.

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APPENDIX A

THE UNIFORMITY ASSUMPTION

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In mathematical modelling and simulation calculations, it is often necessary to make some assumption regarding the distribution of material within a size or specific gravity interval. Examples of this include: determining a mean size/density for the interval, estimating weight fractions contained in subdivisions of the interval, and computing weighted size/density dependent partition functions. More often than not, the uniform distribution is assumed for these purposes, primarily to simplify computation. It is generally accepted that particulate size distributions are seldom uniformly distributed in practice and thus it is necessary to critically evaluate the uniformity assumption. The arguments which follow are concerned with size but are equally applicable to specific gravity.

In order to perform any kind of mathematical analysis it is necessary to adopt a distribution function which will be assumed to characterize the *true* particulate distribution. Many such two- and three-parameter functions are available (e.g., Gaudin-Schuhmann, Rosin-Rammler, Gaudin-Meloy, Roller, Weibull, Bergstrom, ...). However, the Gaudin-Schuhmann function generally provides for the simplest algebra and the fewest numerical computations. On this basis, it will be adopted for the subsequent work. The validity of this cumulative distribution function, with the possible exception of the very coarse sizes, has been demonstrated both in mineral and coal size analyses. The restriction is, however, not nearly so strict as to include the complete size range. In fact, it is only necessary that the function be accurate over a particular interval. (Since two-parameter models require two data points for exact solution, the interval endpoints allow this computation.) Under these conditions, particularly for narrow size intervals, this approximation is about the best one can achieve. The Gaudin-Schuhmann function gives

$$y = [d/k]^a \qquad \text{Eq A.1}$$

where:

- y = cumulative weight fraction passing size d
- k = maximum particle size for the distribution
- a = distribution modulus.

With this function, assumed as representing the true distribution, it is possible to examine errors and computational problems which arise from the uniformity assumption.

Estimating Mean Size

Mathematical models which employ empirical partition curves for computing product distribution factors will either use a characteristic size for a particular interval, or attempt to compute a mean distribution curve and a mass distribution function. The former is commonly encountered in the literature dealing with size classification. For apparent historical reasons, which relate to graphical presentation of data, the geometric mean size has been used. Since, in all of these modelling applications, a mass weighted partition factor over all sizes in the interval is being measured, the characteristic size is, by definition, the mass mean size. Mathematically, the mass mean size is computed as:

$$\bar{d} = \frac{\int_{d_2}^{d_1} d\, m(d)\, dd}{\int_{d_2}^{d_1} m(d)\, dd} \qquad \text{Eq A.2}$$

where:

- $\bar{d}$ = the mass mean size
- $m(d)$ = the density function describing the distribution of mass with size
- d_1, d_2 = the bounds on a particular size interval for which the mass mean size is being evaluated.

Typically, since m(d) is unknown, the characteristic size has been taken by convention to be either the

$$\text{arithmetic mean size, } \bar{d}_a = \left[\frac{d_1 + d_2}{2}\right] \qquad \text{Eq A.3}$$

or

$$\text{the geometric mean size, } \bar{d}_g = [d_1 d_2]^{0.5} \qquad \text{Eq A.4}$$

To determine which of these is more fundamentally correct, m(d) is defined to be the differential form of Equation A.1.

$$m(d) = a\left(\frac{1}{k}\right)^a d^{a-1} \qquad \text{Eq A.5}$$

Substitution of Equation A.5 into Equation A.2 allows an analytical solution for the mass mean size, $\bar{d}$,

$$\bar{d} = \left[\frac{a}{a+1}\right] \left[\frac{d_1^{a+1} - d_2^{a+1}}{d_1^a - d_2^a}\right] \qquad \text{Eq A.6}$$

To simplify Equation A.6, a size ratio is defined as

$$r = d_2/d_1 \qquad \text{Eq A.7}$$

where typically,

$$r = 2^{0.5^n} \; ; \; n = 0,1,2.$$

Equation A.6 is now written as,

$$\bar{d} = d_1 \left[\frac{a}{a+1}\right] \left[\frac{1 - r^{a+1}}{1 - r^a}\right] \qquad \text{Eq A.8}$$

For a = 1, which is the uniform distribution, it is easily shown that Equations A.8 and A.3 are equivalent.

Considering first the arithmetic size, a bias error is defined as

$$e_a = 100\% \left[\frac{\bar{d} - \bar{d}a}{\bar{d}}\right] \qquad \text{Eq A.9}$$

where:

e_a = bias error between the mass mean and the arithmetic mean sizes which can be further simplified to,

Choosing typical values for a and r allows solution for e_a,

$e_a = -1.55\%$ (a = 0.6, r = 0.5)
$e_a = -0.4\%$ (a = 0.6, r = 0.71)

which are sufficiently close to zero to indicate reasonable approximation.

Defining an equivalent form to Equation A.9 for bias error on the geomean size yields the expression

$$e_g = 100\% \left[1 - \frac{(1 - r^a)(a+1)r^{0.5}}{a(1 - r^{a+1})}\right] \qquad \text{Eq A.11}$$

where:

e_g = bias error between the mass mean and the geometric mean sizes which, for typical a and r values above yields

$e_g = 4.26\%$ (a = 0.6, r = 0.5)
$e_g = 1.09\%$ (a = 0.6, r = 0.71).

The approximate break-even point, that is the a value for which

$$|e_g| = |e_a|$$

is approximately a = 0.25, is well below those values normally encountered in particle size analysis. Furthermore, combining Equations A.4 and A.7 and setting the result equal to Equation A.8 shows that for

$$\bar{d}g = \bar{d}$$

the distribution modulus must have a value of a = −.05. The fact that this has no physical significance for Equation A.1 implies that a ≥ 0.

Based on these results it can be concluded that the arithmetic mean size of the interval is generally a better estimate of the mass mean size and hence is the more fundamentally correct convention to be employed.

Before proceeding, it is worthwhile to illustrate the computational convenience in Equation A.3 relative to solving the *more correct* form in Equation A.8.

Arithmetic mean size	***Mass mean size***
(1) $\bar{d}a = \frac{(d_1 + d_2)}{2}$	(1) Compute Y_1 and Y_2 from the sieve analysis data
	(2) Compute the distribution modulus $a = \frac{\log (Y_1/Y_2)}{\log (d_1/d_2)}$
	(3) $\bar{d} = d_1 \left[\frac{a}{a+1}\right] \left[\frac{1 - r^{a+1}}{1 - r^a}\right]$

Clearly, there are many more arithmetic operations which need to be performed to compute $\bar{d}$. The values for e_a are such that it is probably unnecessary to go to this computational expense.

Estimating Weight Fractions in a Subdivided Interval

It is sometimes necessary in simulation calculations to partition a particular size interval and then estimate the weight distribution on either side of the partition. For example, screen models may require such estimates with respect to applying the appropriate partition factor or, alternatively, for estimating the near size frequency. Suppose h is some size in the range

$$d_1 > h > d_2$$

and it is necessary to compute the fraction of material contained in the interval (h,d2), f. Applying the uniformity assumption,

$$f_a = \left[\frac{h - d_2}{d_1 - d_2}\right] \qquad \text{Eq A.12}$$

where:

f_a = an estimate of the mass fraction of material contained in the subinterval $[h, d_2]$, invoking the uniformity assumption

while for the true distribution,

$$f = \left[\frac{h^a - d_2^a}{d_1^a - d_2^a}\right] \qquad \text{Eq A.13}$$

Substitution of Equation A.7 into Equations A.12 and A.13 and defining the ratio,

$$q = h/d_1 \qquad \text{Eq A.14}$$

where:

$$r < q < 1$$

and finally defining a bias error analogous to Equation A.9 yields,

$$e = 100\% \left[1 - \left[\frac{q-r}{1-r} \right] \left[\frac{1-r^a}{q^a - r^a} \right] \right] \qquad \text{Eq. A.15}$$

where:

e = bias error between the estimate, fa, and the *true* value f.

Table A.1 shows the variation of e with q and r.

Table A.1 — Bias error on the prediction of the weight fraction of material contained in the interval (h,d_2)

	Bias error in per cent	
q	r = 0.5	r = 0.71
1	0	0
0.9	2.5	2.3
0.8	5.1	4.6
0.75	6.5	5.9
0.7	7.8	—
0.6	10.8	—
0.55	12.4	—

Of course, the error in the prediction of the material in the interval (d_1,h) varies inversely with those values shown in Table A.1, and is of opposite sign.

Given that the intervals are generally quite narrow, i.e., $r \geq 0.5$, and that the frequency within an interval is therefore minimized, errors such as those shown in Table A.1 are probably tolerable, considering the computational effort involved. Furthermore, errors in these particular computations are probably more than offset if downstream models assume a continuous distribution over the interval of interest in the products, when, in fact a separation has occurred.

Estimating Weighted Partition Functions

Some of the models in simulation calculations utilize weighted partition function values over the interval of interest. This occurs to some extent in both crusher and screen models. To allow analytical or approximate analytical solution it is necessary to:

- assume a functional form for the partition curve, and
- assume a distribution of material within the interval.

With regard to (2), including an equation like A.5 in one of the forms of A.2 involves both parameter estimation and, most probably, a numerical solution. Rather than attempting a general analysis of the problem, consider a particular example.

In his textbook, Lynch(16) presents a sample computation using Whiten's screen model, the basis of which is given in Equation A.16.

$$p(d) = \begin{cases} 1.0 & h \leq d \\ \left[1 - \left[\frac{h-d}{h+w} \right]^2 \right]^m & d < h \end{cases} \qquad \text{Eq. A.16}$$

where:

- $p(d)$ = probability that a particle of size d will report to the screen oversize product
- h = screen throughfall aperture
- d = particle size
- w = wire diameter
- m = the number of *screening trials* a particle is expected to undergo in traversing the screen.

Suppose for the purposes of this calculation that the material is the same as in Lynch's Example 7. Consider the size fraction bounded by (11 314 μm, 5660 μm). Employing the uniformity assumption and the integral approximations implemented by Whiten, the mean value of p(d) is calculated to be,

$$\bar{p}_{a(11314,\ 5660)} = 0.1187$$

where:

$\bar{p}_{a(11314,\ 5660)}$ = mean probability that particles contained in the interval (11 314, 5660) will report to the oversize product, estimated by invoking the uniformity assumption.

Fitting Equation A.1 to this interval yields,

$$a = 0.84 \qquad k = 20\ 410\ \mu m$$

which can be substituted into Equation A.5. With this result and Equation A.16, Equation A.17 is solved by numerical methods to give the *true* estimate of the mass mean probability.

$$p_{(11314,\ 5660)} = \frac{\int_{5660}^{11314} d\ 0.84 \left[\frac{1}{20410}\right]^{0.84} d^{0.84-1} dd}{\int_{5660}^{11314} 0.84 \left[\frac{1}{20410}\right]^{0.84} d^{0.84-1} dd} \qquad \text{Eq A.17}$$

$$\bar{p}_{(11314,\ 5660)} = 0.1152$$

$$\bar{p}_{(11314,\ 5660)} = 0.1152.$$

Note that this value doesn't differ substantially from that obtained by Whiten's methods. However, it does exhibit the bias one would expect based on the material distribution assumptions.

Finally, and for comparative reasons alone, $\bar{d}a$ and $\bar{d}g$ have been computed and substituted into Equation A.16 to examine the estimates of mean probability which would be obtained. The results are,

$$\bar{p}(da) = 0.0186$$

$$\bar{p}(dg) = 0.0067.$$

The large errors so obtained point out the danger of using characteristic sizes with *steep* or near-perfect partition curves.

To summarize, when it is possible to obtain an analytical solution either directly or through approximation techniques, by employing the uniformity assumption, it seems reasonable to do so. However, it does seem, from the scant evidence which is available, that the numerical method of solution is quite cheap, computationally. For example, solution of Equation A.17 by Simpson's 1/3 Method gave identical values when the total number of function (i.e., m(d) or p(d)) evaluations was 7, 11, or 101. Given the overhead of parameterizing Equation A.1 at every interval, it would be advantageous to employ the uniformity assumption even when numerical methods are employed.

Conclusion

On the basis of the foregoing analysis it is recommended that, for modelling and simulation calculations, the uniformity assumption be employed as a reasonable approximation to the distribution of material within a given size or specific gravity interval.

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