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GENFLOW: An Equation-oriented Computer-aid for the Calculation of Ore-dressing Material Balances Using Performance Indicators

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A computer-aid is described that is designed to calculate steady-state material balances for ore-dressing circuits. The program determines the material balance from a specification of the process condition. No mathematical models or data adjustment techniques are employed. As such the program complements existing simulation and material balance 'smoothing' packages. The process condition is specified using performance indicators. These are significant parameters in the industry with which all practising mineral processors are very familiar. The program employs an equation-oriented technique for material balancing and so has had to deal with the difficulties peculiar to that approach.

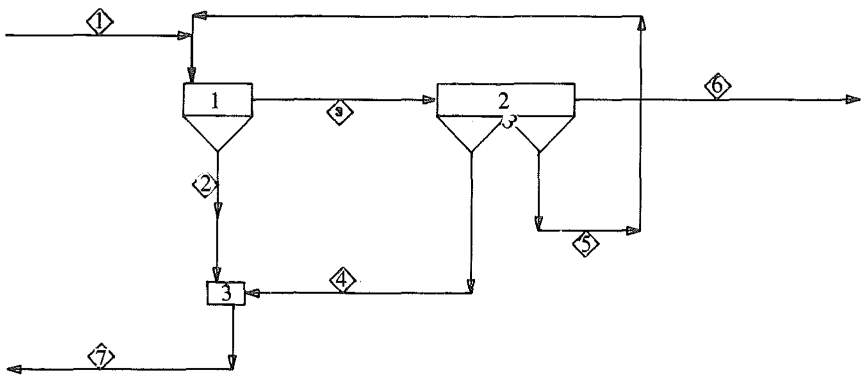
Introduction

A number of flowsheeting computer-aids have been developed recently for the determination of steady-state material balances for ore-dressing circuits. These all fall into one of two categories, i.e. 'simulators',[1,2] in which mathematical models predict how each unit converts feed streams into product streams, and 'smoothing packages',[3,4] in which sampling data are adjusted statistically to provide a consistent material balance. In this paper a computer-aid, GENFLOW, will be described that falls into neither of these categories. This program is designed to calculate a material balance when the process condition is specified exactly rather than being either simulated or inconsistently specified.

The calculation method that GENFLOW employs is essentially that used in conventional metallurgical accounting. Such calculations may be computerized using general purpose spread-sheet programs[5,6] – this option being particularly successful for routine accounting purposes. However, when attempting to perform non-routine material balance calculations spread-sheets can become very unwieldy and cumbersome; this practical difficulty becomes worse the more complex the circuit. GENFLOW has been designed to assist in the calculation of material balances in these non-routine, predictive situations. To the author's knowledge no generally applicable computer-aid has previously been developed and made available that is specifically designed to calculate ore-dressing material balances using the conventional method.

In order to lay a proper foundation for a description of the GENFLOW program it will be useful to review the calculation method it employs. It will also be necessary to

TABLE 1. Illustration of the conventional method for calculation of an ore-dressing material balance



Streams	Assumptions	
1	a) 100 TPH of solids	b) 1,5% mineral
2	a) 15% mineral	b) 80% mineral recovery from new feed
5	a) 3% mineral	b) 10% mass recovery
6	a) 0,1% mineral	
7	b) 12% mineral	

Calculation sequence for the determination of component flowrates

Stream	Component	Mass flowrate (TPH)	Method of calculating flowrate
1	Solids	100	assumption 1(a)
	Mineral	1,5	assumption 1(b)
2	Mineral	1,2	assumption 2(b)
	Solids	8	assumption 2(a)
7	Mineral	1,4118	assumption 6(a)*
	Solids	11,765	assumption 7(a)
6	Solids	88,235	conservation of solids over complete circuit
	Mineral	0,0882	conservation of mineral over complete circuit
4	Solids	3,765	conservation of solids in unit 3
	Mineral	0,2118	conservation of mineral in unit 3
3	Solids	102,222	conservation of solids in unit 1**
5	Solids	10,222	assumption 5(b)
	Mineral	0,3067	assumption 5(a)
3	Mineral	0,6067	conservation of mineral in unit 1

*Mineral recovery over the complete circuit = 94,12% calculated using the two-product formula. This required assumptions 6(a), 7(a) and 1(b).

**Mass conservation of solids across unit 1 and assumption 5(b) provide two simultaneous equations leading to X = 100 + 0,1X − 8 (where X = mass flowrate of solids in stream 3).

review the nature and utility of performance indicators because these have a considerable influence on the design of the program.

Conventional calculation of material balances

Table 1 provides an illustration of the conventional calculation of a simple material balance. The essential features of the method are as follows:

(a) The process condition is defined by specifying the flowrate and/or composition of some of the process streams. Sometimes the definition may include the unit efficiencies of some of the unit operations. The unspecified flowrates and compositions are calculated using conservation relationships that apply in the circuit.

(b) The flowrates, compositions and unit efficiencies used in defining the process condition are widely utilized as indicators of performance. The significance of these performance indicators in the industry is crucial and is discussed in the next section. It is an important feature of the conventional method that only these important indicators are used to define the material balance problem.

(c) The same material balance problem may be defined in a wide variety of ways. For example, the balance in Table 1 requires that at least one flowrate be specified, but it is not important which flowrate this is. Further, the specification of tailings or concentrate grades could be replaced by the specification of the overall mass or mineral recovery. This feature of the calculation method allows a mineral processor much flexibility in the way he can define a problem. In some situations[7] this can be very useful. However, there is a price to be paid for such flexibility because not all attempts to specify the process condition may be valid. The diagnosis of why any particular attempt is invalid is a difficult problem in the general case. This problem will be discussed later in some detail.

(d) The material balance for a continuous process is established once the flowrates of all the relevant components in all the process streams have been determined. Which components might be relevant is discussed later. In the example the relevant stream components are total dry solids and contained mineral.

(e) In Table 1 the set of equations is solved primarily by direct substitution. In general simultaneous solution is more appropriate. This presents no computational difficulty because the relationships are nearly always linear.

Performance indicators

Performance and performance indicators

The basic objectives of any processing organization are to maximize income and to minimize costs. The performance of the organization is the measure of the extent to which these financial objectives are achieved and maintained. For practical purposes the basic financial objectives of a processing operation need to be translated into equivalent technical objectives so that performance may be assessed in technical terms.

The technical objectives that relate to maximizing income are the production objectives of maximizing the quantity of saleable products while achieving the required quality. The usual understanding of technical performance is the performance that relates to these production objectives.

The technical objectives that are associated with minimizing costs involve a wide variety of activities and technologies. From the perspective of the processing technology these cost minimization objectives - though very important - are secondary to production objectives. The most basic indicators of performance therefore assess the production rate and quality of the saleable products. When considering the performance of parts of the circuit the same types of performance indicators are required, but these will refer to the production rate and quality of the material in internal process streams.

In devising suitable indicators of performance two aspects must be considered. Firstly, an assessment is required of the extent of the achievements of the processing effort with respect to production objectives. This focuses on the actual production status. Secondly, an assessment is required of the efficiency of the processing effort. This focuses on the performance that would be expected given good operating practice. It allows an evaluation of how well resources have been used and in particular the quantity and quality of saleable or internal products that have been produced from each unit of feed.

The production rate and composition of products are the simplest measures of the extent of performance. Quality measures other than composition may be of interest, but composition is the most basic.

When wishing to assess the efficiency of an operation attention is focused on the change that the operation seeks to bring about. Efficiency measures must evaluate the degree to which the actual change that is brought about approaches the ideal. In ore-dressing operations the change sought is the transformation of feed material into products by the separation of valuable from non-valuable components. There are two ideal changes associated with this transformation. The first is that change which results in complete extraction of values from the feed to the products. This relates directly to the objective of maximizing production rates. An efficiency measure based on this ideal change would be a recovery type of measure which, for example, would compare the flowrates of contained values in feed and product streams.

The second ideal change that efficiency measures might address is the change which results in a perfect separation of values from non-values. The measure associated with this change deals with the quality of products. However, such measures of efficiency are not as useful, or indeed as meaningful, as recovery indicators. This is because the ideal change envisaged - if achieved - would maximize the quality of products whereas the relevant production objective is to achieve an acceptable - not a maximum - quality. Efficiency measures based on the quality of material have, however, been defined. These take the form of upgrading ratios where the compositions of feed and product streams are compared.

Commonly used performance indicators

The review so far has shown that only four types of performance indicators are required in order to describe processing performance at a production level. Measures of flowrate and composition quantify production status while recovery measures and upgrading ratios describe the efficiency of performance.

The performance indicators that are used in practice form a surprisingly small set. This is because the flowrate, composition or efficiency measures refer to specific stream components, and there are only a few types of stream components that are relevant when assessing performance at a production level. These will always include dry solids and one or more of the following: contained water, contained mineral, solids in size classes, solids in specific gravity classes.

Solids volume must be declared as a relevant stream component if solids sg is required as a quality indicator. (Notice that solids sg may be treated as a special kind of composition indicator. It provides a relationship between the components of solids volume and solids mass just as grade provides a relationship between the components of contained mineral and solids mass.) Other stream components may be relevant when production objectives require a more detailed assessment of the particulate nature of the material. This is usually only important when examining parts of a circuit. The descriptions needed will very rarely deal with anything more detailed than the mineral contained in size or sg classes, or possibly the solids or contained mineral in each sg class in each size class.

From the above it is seen that seven different types of stream component may be relevant in any given ore-dressing operation when assessing performance at a production level. These are listed in Tables 2 and 3 along with the more commonly used compositional and efficiency indicators with which they may be associated.

The usage of performance indicators

The importance of performance indicators derives from their role in the control and optimization of the performance of a process. This requires the quantification of performance targets, the measurement of actual performance and an understanding of the factors which can be manipulated to make the two coincide.

The importance of performance indicators in the quantification of performance - achieved or targeted - has already been discussed. Performance indicators are also important in the understanding of how the process may be manipulated. This is because a mineral processor's understanding of the factors that influence the process is very often summarized in terms of how

TABLE 2. Commonly used compositional/quality performance indicators

Component type	Compositional performance indicators associated with component type
Total solids	Reference component when specifying composition
Water	Moisture, % solids
Contained mineral	Grade
Total solids in size class	Size distribution
Total solids in sg class	Sg distribution
Mineral contained in size or sg class	Grade
Volume of solids	Specific gravity

TABLE 3. Commonly used recovery-type efficiency indicators

Component	Common performance indicator associated with component type
Total solids	Mass recovery, solids recovery
Water	Water recovery
Contained mineral	Mineral recovery
Solids in size class	Sizing efficiency
Solids in sg class	Sg separation efficiency, epm*
Mineral contained in size or sg class	Nil
Volume of solids	Nil

* An efficiency parameter used in certain expressions describing a Tromp curve.

these factors influence relevant performance indicators. To give a simple example, the influence of collector addition rate might be summarized as 'an increase in collector addition rate improves recovery at the expense of grade'.

A given performance indicator may convey to an experienced mineral processor far more information than the specific detail quantified. To illustrate this, consider grade used as a performance indicator in a flotation circuit. Under different operating circumstances the grade of a rougher concentrate might provide by implication an indication of the pulling rate on the cells, the feed grade or the correctness of reagent addition rates. It may also give some indication of the extent of recirculation of scavenger concentrate, or the coarseness of the grind or even information on the condition of equipment.

It is clear that performance indicators have a very basic and important function in process operations. This influences the way communications in the industry are conducted. The indicators used in processing operations have become incorporated into the jargon that facilitates efficient discussion on production matters. As a result these indicators are used in communications across the industry, from the consulting metallurgist down to the operator, from vendors of equipment and consumables to instrumentation and other engineers associated with the operation. They are used and understood by research and development people and by design engineers.

In summary, performance indicators are fundamental to the understanding and communication of matters pertaining to process performance. They allow a complete description of process performance at a production level and can be used in defining material balance problems, as will be shown later. The conventional method for calculating material balances is important not only because it is widely used, but also because it allows a mineral processor the ability to define a material balance problem using only the performance indicators which are so fundamental in his own understanding of a process.

The design of GENFLOW

Formalization of the calculation method

For any given ore-dressing circuit consisting of S streams and U unit operations let there be C component types that are of interest. The material balance for the circuit is established when CS component flowrates have been calculated or defined. Let X be a vector of these CS component flowrates. In order to identify the stream number i and the component type j to which a component flowrate refers the elements of the vector X will be represented as follows:

$$\underset{\sim}{X} = (X_{11}\ X_{12}\ \cdots\ X_{ij}\ \cdots\ X_{SC}) \qquad [1]$$

In order to define the material balance problem, information must be provided that will generate exactly CS independent equations in X. Usually these equations are all linear, as will be shown. The problem of calculating the material balance therefore reduces to solving a matrix equation in X.

The CS equations that are required to define the problem are derived from two sources - from conservation considerations and from a specification of process condition. Each of these sources is examined in turn.

The set of equations describing the material balance problem must include every independent conservation relationship that applies in the circuit. If every type of stream component is conserved across each unit operation in the process, then CU independent conservation expressions may be developed. These will have the following (linear) form:

$$\sum_{\text{feeds}} X_{fj} - \sum_{\text{products}} X_{pj} = 0 \qquad [2]$$

where j represents the component type conserved, f refers to a stream feeding the unit and p a product stream.

The description of certain particulate characteristics requires that some types of stream components be defined that may not always be conserved across unit operations. The solids in a given size class is one example. Clearly, such a component is not conserved through a size reduction operation. Let there be A occurrences of this type of situation in a process so that in general the number of independent conservation expressions that can be generated for a circuit is CU-A.

The second source of information used in generating appropriate equations for the definition of the material balance problem is the set of performance indicators that define the process condition. The number of equations, N, that must be provided from this source is:

$$N = C(S - U) + A \qquad [3]$$

With the exception of upgrading ratios each of the different types of performance indicators described may be used to define simple linear equations in X. Specification of a flowrate, F, leads to Equation [4], percent composition (grade), G, to Equation [5]; and percent efficiency (or recovery), R, to Equation [6].

$$X_{ij} = F \qquad [4]$$

$$100\ X_{ij} - G\ X_{is} = 0 \qquad [5]$$

$$100\ X_{pj} - R\ X_{fj} = 0 \qquad [6]$$

(i - relevant stream; j - relevant stream component (may refer to dry solids, water or other components); s - dry solids component)

All of the performance indicators listed in Tables 2 and 3 will lead to linear equations of the same or very similar form to Equations [5] and [6]. Upgrading types of efficiency indicators are not included in this treatment or in the GENFLOW program because they are not frequently used in calculating material balances and they do not form linear equations in X.

It is not difficult to see that conservation relationships and performance indicators are sufficient to define for any ore-dressing circuit any steady-state material balance that might be needed when assessing technical performance. Conservation relationships - Equation [2] - and composition indicators - Equation [5] and Table 2 - alone make available independent equations that are sufficient to relate all the component flowrates that may be of interest. These equations each relate the flowrate of a stream component to that of others. Therefore, provided that at least one flowrate is specified, it is possible to calculate the material balance of any ore-dressing circuit using only these very simple relationships.

Program specifications for GENFLOW

The GENFLOW program must provide the following essential functions:

(a) Flowsheet definition: this defines the number of streams and units (S and U) and their connectivity. This function must also provide information that will assist the determination of A, the number of conservation relationships that do not apply but are implied by the flowsheet.

(b) Specification of the number, C, and the nature of the stream components common to each process stream.

(c) Provision of linear equations to define the material balance problem. GENFLOW must derive the CU-A conservation equations by reference to the flowsheet. For the remaining N equations needed the user must be able to allocate performance indicators to streams and to quantify these indicators appropriately. The way in which the program requires the user to do this is determined by the nature of the user interface. Details about the GENFLOW interface have been given elsewhere.[7] There are a number of difficulties associated with selecting an appropriate set of performance indicators. These are discussed in the next section.

(d) Solution of the set of equations defining the material balance problem. These equations will be sparse and linear, and are best solved by Gaussian elimination.

(e) Output of results, starting data and important diagnostics. Examples of some of these are given in the appendix.

Selection of an appropriate set of performance indicators

It is well known that with any generalized equation-writing and solving program the great flexibility that is available for the definition of a problem allows significant opportunities for defining the problem badly such that no solution is possible.[8] If this happens it can be very difficult to establish where and why the problem is ill-defined. The program must be able to analyse the problem definition and to provide diagnostics to assist the user in correcting this error. It is possible here to give only a brief overview of how the GENFLOW program tackles this problem of diagnostics.

There are three constraints that must be satisfied for correct specification of the material balance problem. These are that exactly CS equations must be defined, that they are mathematically consistent (i.e. independent), and that the definition of the problem must be consistent from a processing point of view. A user faced with trying to correct the definition of an ill-posed problem requires assistance, firstly, in identifying which constraint has not been properly met and, secondly, to provide information as to why. The assistance that may be provided is discussed as it relates to each of the three constraints mentioned.

Finding the correct number of equations

The user is required to provide performance indicators that will generate exactly N equations. Assistance here may be provided by indicating the number of equations required and the number which may be derived from the performance indicators specified.

Finding mathematical inconsistencies in the problem definition

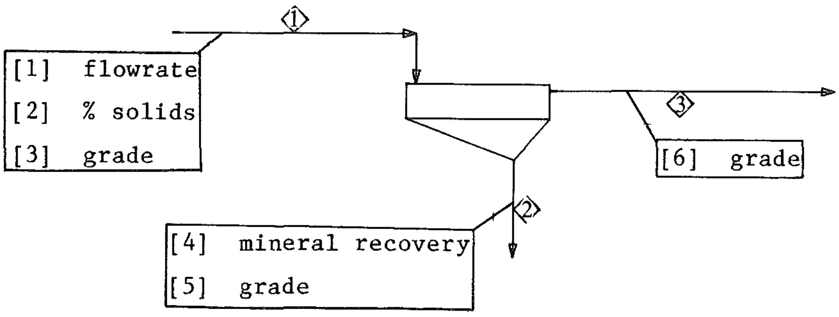
Here the user is faced with the knowledge that although the correct number of equations has been specified, they form a singular system. Providing meaningful diagnostics in this situation is a particularly difficult problem.

The most common cause of mathematical inconsistency in a set of equations defining a material balance problem is 'structural' singularity.[8] A very simple example of this type of problem is given in Figure 1. As can be seen, the set of performance indicators used to define this problem will always lead to a singular set of equations, no matter what numerical values are used in the specifications. This is because the mineral balance is over-defined and the water balance under-defined.

Assistance in identifying which equations are causing the inconsistency may be obtained by analysing the 'structure' of the coefficient matrix. Essentially, this involves row rearrangement in an attempt to form a diagonal that contains no zero elements. If it is not possible to do this then the system of equations will be singular.[8] Information about the possible causes of the inconsistency may be obtained by identifying which elements in the diagonal are zero. Although such information cannot in general be unambiguous it proves to be very useful in providing meaningful clues to the user as to the possible causes of inconsistent problem definition. Some further explanation and a simple example will illustrate how GENFLOW provides assistance in this area.

Figure 2 shows the structure of the inconsistent system of equations derived for the material balance problem described in Figure 1. The structure is shown in the form of an occurrence matrix which consists of unit and zero elements that reflect the position of the non-zero elements in the coefficient matrix. The row arrangement required to examine the structure is implied by ringing the element in each row that will be on the diagonal after the row rearrangement. In each row the variable associated with the ringed coefficient is known as the 'output variable' of the equation which the row represents. When the system of equations is structurally singular it will not be possible to define a complete set of CS output variables. At least one equation will be dependent and have no output variable, i.e. it will have a zero element on the diagonal.

The analysis of the structure of the occurrence matrix in Figure 2 indicates that no output variable can be assigned to Equation [6]. This is a dependent equation



Notes:

(a) Three component types are relevant in each stream and are identified by component type number 1 = solids, 2 = water, 3 = contained mineral.

(b) Performance indicators have been allocated to three process streams. Each indicator generates one equation. Numbers in square brackets are placed against each indicator for purposes of association with the equations derived from them.

FIGURE 1. Specification of a simple material balance problem that leads to structural singularity

Column no. →	1	2	3	4	5	6	7	8	9	
X_{ij} →	X_{11}	X_{12}	X_{13}	X_{21}	X_{22}	X_{23}	X_{31}	X_{32}	X_{33}	
[1]	1									
[2]	1	1								
[3]	1		1							
[4]			1			1				
[5]				1		1				Over-definition
[6]							1		1	Dependent equation found
[7]	1			1			1			Dependency/inconsistency
[8]		1			1			1		
[9]			1			1			1	

Equation number

Under-definition : Equation [8] may provide an output variable for one or other but not both of the variables X_{22} and X_{32}

Notes :

(a) Equations [1] to [6] are derived from performance indicators as shown in Figurel. Equations [7] to [9] are derived from conservation considerations.

(b) A '1' in the occurrence matrix indicates a non-zero coefficient in the equivalent coefficient matrix for the system of equations describing the material balance problem.

(c) Output variables for each equation are ringed.

FIGURE 2. Structure of the occurrence matrix for the material balance problems shown in Figure 1

and its dependency may be discovered by identifying which equations possess the output variables corresponding to the variables in the dependent equation. In this case dependencies exist between Equation [6] and Equations [7] and [9]. The analysis suggests that a problem of over-definition exists that involves one of the equations derived from the grade of tailings and the conservation of solids and mineral across the unit.

Identifying which variables cannot be

assigned as output variables suggests where the problem may be under-defined. It is clear that either X_{22} or X_{32} (water flowrates in streams 2 and 3) but not both may be assigned as output variables. This suggests that the water balance is under-defined.

Unfortunately, the assistance that can be provided by the means described is not unambiguous because the set of output variables is not in general unique.[9] This means that different assignments of output variables are possible and hence different dependencies and unassigned variables may be detected. In GENFLOW several different assignments of output sets are attempted and lists are provided of the dependencies and unassigned variables found. In addition, a description of the first set of output variables assigned can be supplied. The assistance that these measures provide is not optimal but it proves in most situations to be very effective in providing useful clues to the user as to where his specification of the problem is inappropriate.

A system of equations may be singular not for structural reasons but because the numerical values of elements in the coefficient matrix are such as to introduce dependencies. A simple illustration is given in Figure 3. As can be seen, the system of equations is not structurally singular, and a complete set of output variables may be defined (see Figure 4a). However, the numerical values of the coefficients for Equations [4] and [5] (see Figure 4b) are such as to make the system of equations singular. The problem in this case is related to the recycle stream.

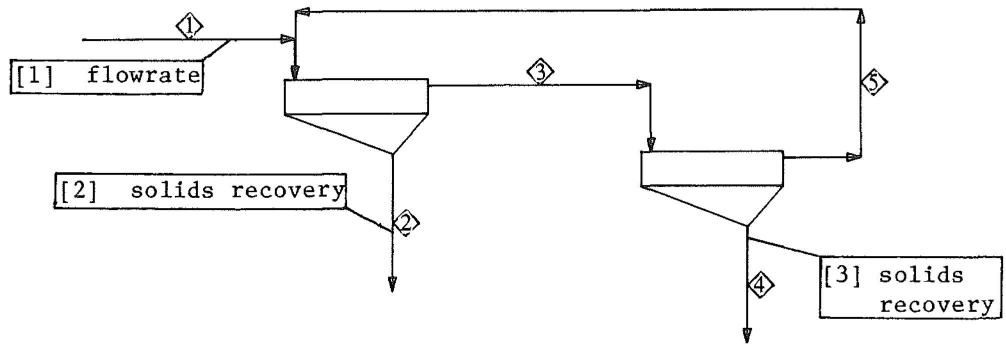
Finding the cause of singularity is more difficult when the singularity is numerical rather than structural in nature. It does appear, however, that numerical singularity is a less frequently encountered problem than is structural singularity,[8] and this has been borne out by experience with GENFLOW. Currently the assistance that GENFLOW provides is to inform the user when the singularity is numerical. In addition the row elimination at which the problem was detected is noted and the user informed of which performance indicators or conservation expressions are involved. Again the assistance is not optimal but it is helpful in most situations.

Finding process inconsistencies in the problem definition

A material balance may be defined in such a way that although the correct number of equations has been provided and these are all mathematically consistent, yet the material balance predicts unattainable process conditions. Negative flowrates are the most common result of this problem. Algorithmically this is the most difficult of the three diagnostic problems to solve.[8] However, when the problem does occur the user does have available a calculated material balance - albeit with some unattainable flowrates. By examining this balance the user may obtain clues as to the nature of the difficulty. A user's experience with the manual calculation of balances is useful in pinpointing the inappropriate specifications. GENFLOW in this case merely highlights that the problem exists and where, and leaves it to the user to make the necessary analysis and rectification.

Conclusions

The flowsheeting computer-aid that has been described is interesting from a number of points of view. It provides a mineral processor with a computerized means of establishing a material balance on the basis of an exact specification of process



Notes:
(a) Only the solids component is considered in this problem.
(b) Performance indicators and the equations derived from them are indicated in the same way as in Figure 1.

FIGURE 3. Specification of a simple material balance problem that leads to numerical singularity

(a)

Column no. →	1	2	3	4	5
X_{ij} →	X_{11}	X_{21}	X_{31}	X_{41}	X_{51}
[1]	1				
[2]	1	1			
[3]	1			1	
[4]	1	1	1		1
[5]			1	1	1

(b)

Column no. →	1	2	3	4	5
X_{ij} →	X_{11}	X_{21}	X_{31}	X_{41}	X_{51}
[1]	a				
[2]	b	c			
[3]	d			e	
[4]	1	−1	−1		1
[5]			−1	1	1

Equation Number

Notes:
(a) Refer to Figure 2 for details on the setting up of an occurrence matrix.
(b) Equations [4] and [5] are derived from conservation considerations.
(c) For the purpose of the point that is to be made when referring to Figure4(b) the values of the coefficients a,b,c,d, and e are not important.

FIGURE 4. The occurrence and coefficient matrices for the material balance problem shown in Figure 3
(a) Occurrence matrix (b) Coefficient matrix

condition. Process condition is specified using performance indicators only. These are fundamental parameters in the industry and are basic to the understanding of process performance.

As a final point it is interesting to view the GENFLOW program from a simulation perspective. All known ore-dressing simulators use the sequential-modular approach where mathematical models are provided as modules for each unit operation.[1,2] The material balance is then established sequentially by following the material flow through the circuit and simulating in turn how each unit converts feed streams into products. In the design of chemical engineering simulators there is an ongoing interest in the equation-oriented technique which has a number of advantages over the sequential-modular approach.[8] GENFLOW is an example of an equation-oriented simulator, but is a limiting case because the equations are linear and no mathematical models are used. However, it has had to deal with many of the difficulties associated with this approach. The solutions it has attempted are therefore of interest when the program is viewed as a first step towards the development of a more general equation-oriented simulator for ore-dressing circuits.

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Appendix

EXAMPLE 1. Calculation of a material balance for a coal washing circuit.

This particular problem was selected because of the complex suite of stream components that it requires. These include solids, size classes (5), 11 sg sub classes in each size class, and the ash content of each sg sub-class. At least 111 component flowrates must be calculated for each stream.

The time taken to solve this problem was 51 minutes, broken down as follows :

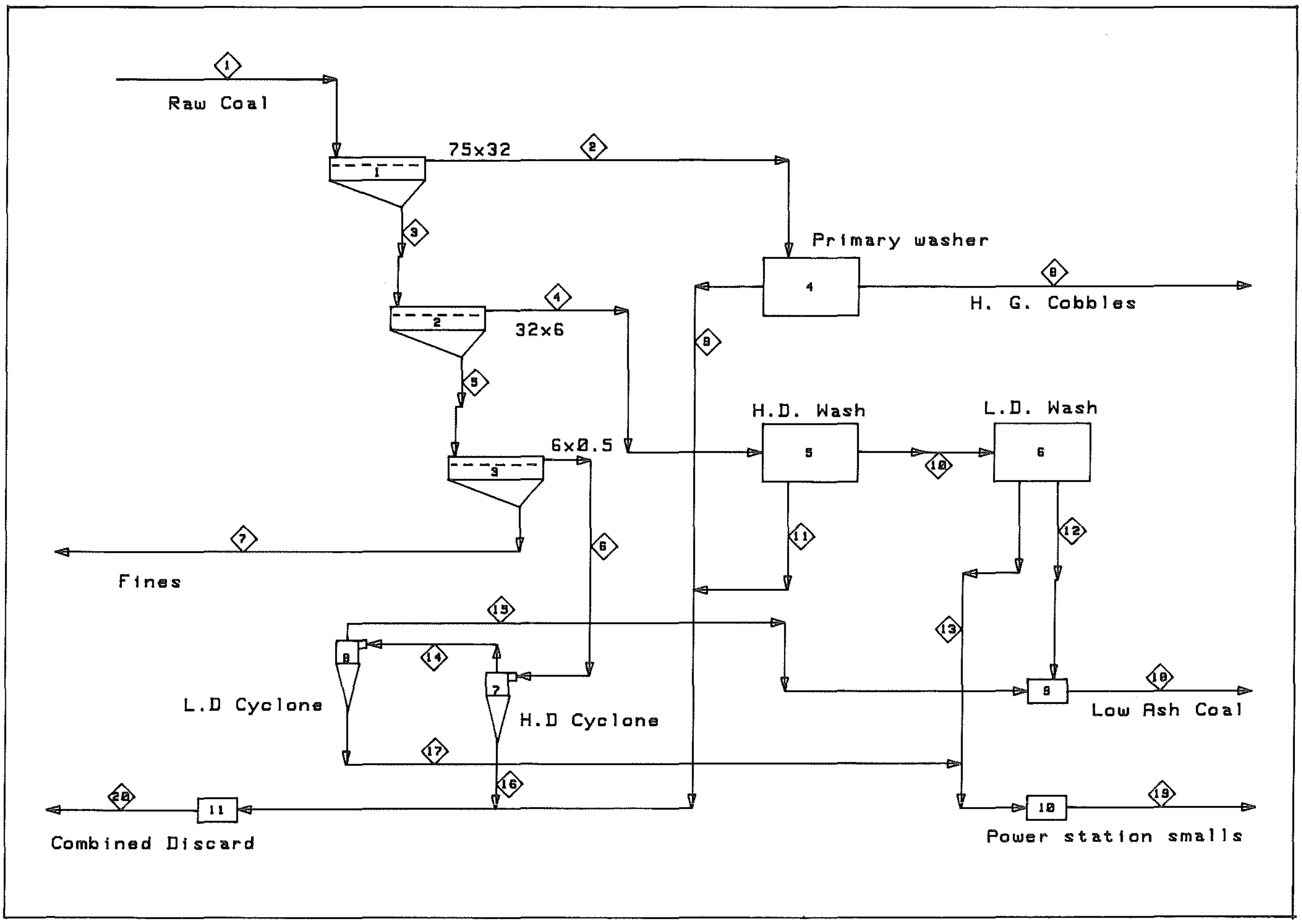
Drawing the flowsheet - 8 minutes

Labelling the flowsheet - 9 minutes

Defining stream components - $1\frac{1}{2}$ minutes

Description of process condition - 23 minutes (The majority of this time was spent on specifying and correcting the washability data of the feed)

Calculating the balance - $9\frac{1}{2}$ minutes.



Description of process condition:

The following is an extract from the program output which describes the process condition that has been specified by the user.

```
 PROCESS DATA ASSUMED IN THE CALCULATION OF MASS BALANCES
                FOR Coal Washery

      Components common to all streams are as follows:-
       : Solids : Ash
       : 5 size classes : 11 SG classes
      mineral component/s in each size/SG sub-class


Stream No: 1 Raw Coal
         Stream flows from Battery limits to Unit No: 1
         - TPH Solids = 950
         - Size distribution (Wt%)
             -75   +32   mm = 24.6
             -32   +12   mm = 27.4
             -12   +6    mm = 15.5
             -6    +.5   mm = 26.1
             -.5     mm     = 6.4
         - SG distribution   (Wt%)
           SG Distrib in Size class -75   +32   mm
             -2.4  +1.75 T/ = 16.2
             -1.75 +1.7     = 2.4
             -1.7  +1.65    = 3.2
             -1.65 +1.6     = 3.4
             -1.6  +1.55    = 5.8
             -1.55 +1.5     = 9.2
             -1.5  +1.45    = 12.3
             -1.45 +1.4     = 14.9
             -1.4  +1.35    = 17.2
             -1.35 +1.3     = 13.9
             -1.3           = 1.5
           SG Distrib in Size class -32   +12   mm
             -2.4  +1.75 T/ = 9.9
```

etc

```
Unit No: 3
          - SIZE Separation:  Cut point = .5 mm
            : Separation efficiency = 90%

Unit No: 4 Primary washer
          - SG Separation:  Cut point = 1.7 kg/l
            : Imperfection (Prob err/ep) = .02

Unit No: 5 H.D. Wash
          - SG Separation:  Cut point = 1.55 kg/l
            : Imperfection (Prob err/ep) = .02

Unit No: 6 L.D. Wash
          - SG Separation:  Cut point
```

etc

Calculated material balance

No	STREAM NAME	Coal Washery SOLIDS TPH	wt % Ash	wt % -75mm +32mm	wt % -32mm +12mm	wt % -12mm +6mm	wt % -6mm +.5mm	wt % -.5mm
1	Raw Coal	950.00	19.75	24.60	27.40	15.50	26.10	6.400
2	75x32	233.70	24.09	100.0	-	-	-	-
3		716.30	18.33	-	36.34	20.56	34.62	8.488
4	32x6	407.55	19.00	-	63.87	36.13	-	-
5		308.75	17.44	-	-	-	80.31	19.69
6	6x0.5	254.03	17.21	-	-	-	97.61	2.393
7	Fines	54.72	18.53	-	-	-	-	100.00
8	H. G. Cobbles	188.68	14.96	100.00	-	-	-	-
9	H.G.C. Discard	45.02	62.36	100.0	-	-	-	-
10	H.D. Floats	294.76	11.86	-	63.78	36.22	-	-
11	H.D. Sinks	112.79	37.66	-	64.11	35.89	-	-
12	L.D. Floats	130.90	7.508	-	65.73	34.27	-	-
13	L.D. Sinks	163.86	15.35	-	62.22	37.78	-	-
14	Cyc H.D. Floats	176.20	11.60	-	-	-	97.76	2.243
15	Cyc L.D. Floats	108.34	8.880	-	-	-	97.57	2.434
16	Cyc H.D. Sinks	77.83	29.90	-	-	-	97.27	2.733
17	Cyc L.D. Sinks	67.86	15.94	-	-	-	98.06	1.938
18	Low Ash Coal	239.25	8.129	-	35.96	18.75	44.18	1.102
19	Power station smalls	231.72	15.52	-	44.00	26.72	28.72	0.568
20	Combined Discard	235.64	39.82	19.11	30.69	17.18	32.12	0.903

Calculated material balance showing the distribution of solids among the different specific gravity classes

No	STREAM NAME	Coal Washery SOLIDS TPH	wt % -2.4 +1.75	wt % -1.75 +1.7	wt % -1.7 +1.65	wt % -1.65 +1.6	wt % -1.6 +1.55	wt % -1.55 +1.5	wt % -1.5 +1.45	wt % -1.45 +1.4	wt % -1.4 +1.35	wt % -1.35 +1.3	wt % -1.3
1	Raw Coal	950.00	10.28	2.234	2.992	4.408	6.385	10.67	14.05	16.41	14.79	13.11	4.677
2	75x32	233.70	16.20	2.400	3.200	3.400	5.800	9.200	12.30	14.90	17.20	13.90	1.500
3		716.30	8.345	2.180	2.925	4.737	6.577	11.16	14.61	16.91	14.00	12.85	5.713
4	32x6	407.55	9.286	2.272	3.036	4.453	6.236	11.53	14.55	16.66	15.08	13.61	3.289
5		308.75	7.103	2.058	2.777	5.112	7.026	10.67	14.70	17.23	12.57	11.84	8.914
6	6x0.5	254.03	6.134	1.919	2.622	4.662	7.355	11.14	15.84	18.87	10.84	12.07	8.550
7	Fines	54.72	11.60	2.700	3.500	7.200	5.500	8.500	9.400	9.600	20.60	10.80	10.60
8	H. G. Cobbles	188.68	-	0.916	2.742	3.869	7.060	11.36	15.22	18.45	21.30	17.22	1.858
9	H.G.C. Discard	45.02	84.09	8.619	5.118	1.433	0.519	0.165	0.044	0.011	-	-	-
10	H.D. Floats	294.76	-	-	0.049	0.402	2.515	11.29	18.80	22.77	20.81	18.81	4.548
11	H.D. Sinks	112.79	33.55	8.194	10.84	15.04	15.96	12.15	3.433	0.705	0.109	0.017	-
12	L.D. Floats	130.90	-	-	-	-	-	-	0.117	6.306	41.09	42.24	10.24
13	L.D. Sinks	163.86	-	0.011	0.088	0.723	4.525	20.30	33.73	35.92	4.604	0.093	-
14	Cyc H.D. Floats	176.20	-	0.213	0.548	1.724	4.371	9.436	16.98	23.26	14.42	16.71	12.33
15	Cyc L.D. Floats	108.34	-	-	0.028	0.184	0.928	3.725	11.22	22.46	17.76	23.64	20.05
16	Cyc H.D. Sinks	77.83	20.02	5.782	7.316	11.32	14.11	14.98	13.26	8.934	2.724	1.552	-
17	Cyc L.D. Sinks	67.86	-	0.545	1.378	4.182	9.867	18.55	26.18	24.54	9.090	5.663	-
18	Low Ash Coal	239.25	-	-	0.013	0.083	0.420	1.687	5.145	13.62	30.53	33.82	14.68
19	Power station smalls	231.72	-	0.168	0.466	1.736	6.089	19.79	31.52	32.59	5.918	1.724	-
20	Combined Discard	235.64	38.74	7.479	8.584	11.21	12.40	10.79	6.031	3.290	0.953	0.521	-

EXAMPLE 2. Diagnostic report on the material balance problem given in Figure 1.

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ANALYSIS OF INFORMATION PROVIDED FOR MASS BALANCE CALCULATION
Summary Report

For unit 1
the amount of information provided is correct but it is not consistent

Flowrates for one or more of the following stream components can't be calculated
 - water in Stream 3

Dependant equations (To help in identifying extra or dependant data items)
The following sets of equations were found to be dependant
Set 1   (When examining component = mineral)
 1) Equation formed from conservation of mineral through unit 1
 2) Equation formed from Grade for stream 3
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