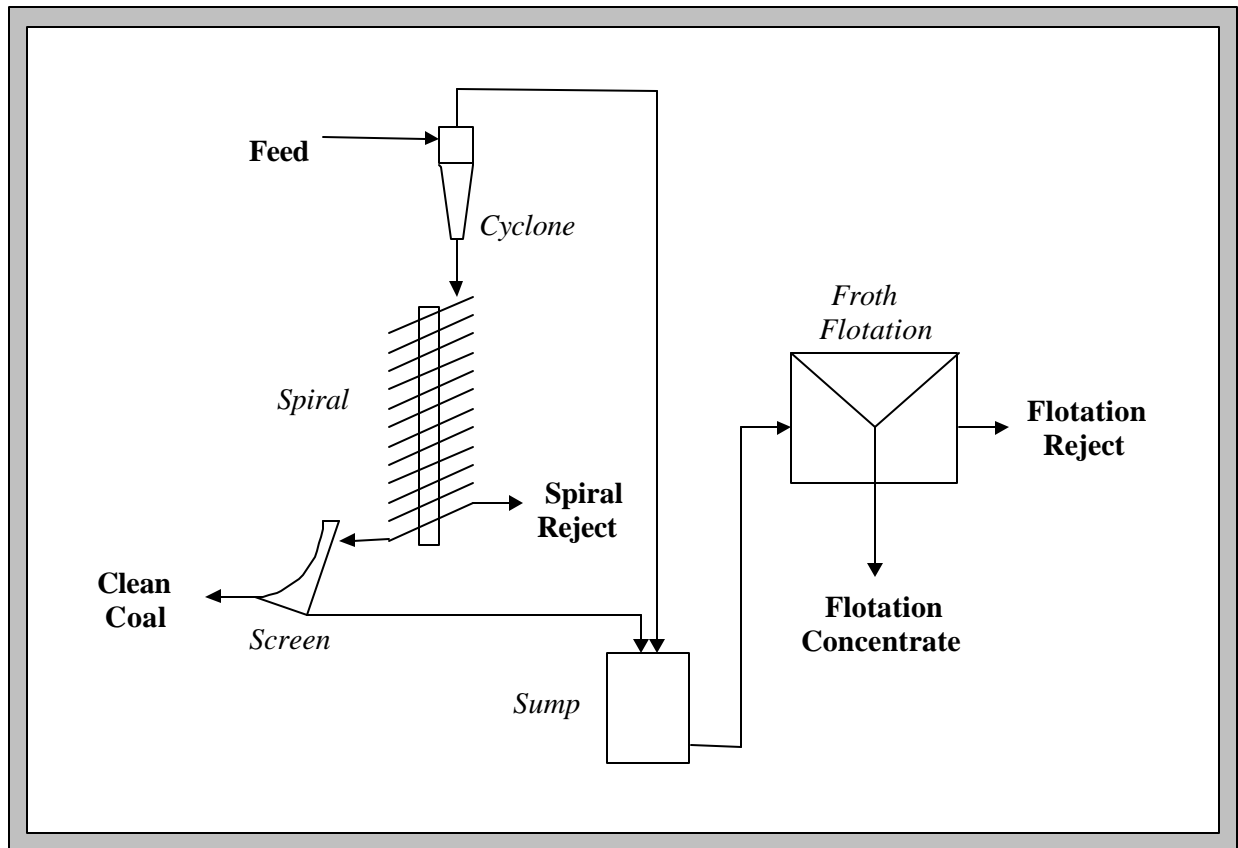


--- TECHBAL ---

Flowsheet Mass Balance Spreadsheet

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Version 1.1

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Introduction

A process flowsheet describes the sequence of unit operations that are performed in a coal preparation plant. The flowsheet (or any part of the flowsheet) can be represented using a series of nodes and streams. A node represents a unit operation as either a junction (two streams which combine to form a single stream) or separator (one stream that is separated in two streams). A series of material balance expressions can be constructed for each node in the flowsheet. For example, consider the following expressions for a simple separator:

$$F = C + T$$
$$Ff = Cc + Tt$$

where F, C and T are the respective mass flow rates of the feed, concentrate and tailings streams and f, c and t are the respective assays which represent the content of a given component in these streams. Using these balances, an expression for concentrate yield (Y) can be derived as:

$$Y = 100 (C/F) = 100(t-f)/(t-c)$$

This expression is known as the two-product formula. Using this formula, the mass flow rates of the concentrate (C) and tailings (T) streams can be calculated provided that the feed stream mass flow (F) and all assays (f, c and t) are known.

A common problem in using the two-product formula is that a unit operation (or combined group of operations) is often overdefined, i.e., multiple sets of assays are available which can be independently used to calculate the yield. For example, common assay values for coal include ash, sulfur, Btu/lb, etc. As with most experimental programs, there is some degree of error associated with the data collection procedures. Thus, the experimental assays will often provide different estimates of the flow rates.

Two solutions are possible to resolve this ambiguity. One would be to ignore some of the measured data. The second would be to adjust the measured assays to

create a new consistent data set that satisfies all the mass balance equations. The latter is obviously the more desirable approach. Adjustment of the mass balance data must meet two criteria: (i) all mass balance equations must be satisfied and (ii) the total adjustment made to the data set must be a minimum.

Numerical methods that can be used to solve the material balance problem include Lagrangian Multipliers (Wiegel) and Direct Search Techniques (Mular). Computer packages that use the numerical methods include: MBS (Hockings, 1967, Michigan Tech), MATBAL (Weigel, 1970, International Minerals Corporation), MATBAL2 (Laguitton, 1979, CANMET), ONEBAL (Wiegel, 1979) and BILMAT (Hodouin, 1980). A material balance program has also been developed at Virginia Tech using a commercial spreadsheet package. This package is capable of handling up to 10 nodes, 20 streams and 5 assays. This spreadsheet program is known as TECHBAL.

Procedure for Using Techbal

Step I – Load Software

1. Make sure that Microsoft Excel (95 or later) is loaded on your computer.
2. Run Excel and determine whether the “Solver Add-In” is has been loaded. This option should be listed under the **TOOLS** menu in Excel. If you do not see **Solver** under this menu, click on **Add-Ins...** and select the box next to **Solver Add-In** and click **OK** to

activate the product. If you have problems, complete directions for installing “Solver” are described in the Excel Help menu.

3. Under the **File** menu, open the **Techbal.xls** spreadsheet from the file where you have saved the program. You may wish to save this master spreadsheet under a subdirectory where the original file cannot be accidentally deleted.
4. Note that areas in the spreadsheet where data may be entered are colored grey. Values entered by the user will appear in blue text. The other regions in the spreadsheet are protected to prevent accidental deletions.
5. A demonstration file called “Techbal-demo.xls” has been provided to show how data should be entered in the spreadsheet. The information related to this example is discussed later in these instructions (see bottom of page 5). If you have not previously used Techbal, you may wish to open this spreadsheet first.

Step II - Enter the Flowsheet Connection Matrix

1. Select the **MATRIX** page of the spreadsheet by clicking on the appropriate tab at the bottom of the page. This is the page where you will enter the information that describes your particular flowsheet.
2. Enter a description of your circuit in the area titled **CIRCUIT** (Row 6).

3. Enter the names of the unit operations (nodes) in your flowsheet beneath the NODE title bar (Row 9). You may use up to 10 nodes.
4. In the column labeled STREAM, enter the names of all of the streams that connect the unit operations in your flowsheet (Column A). You may use up to 20 different stream names.
5. Within the matrix defined by the nodes and streams, enter a -1 or +1 to indicate whether each stream exits or enters the first unit operation (node). The value zero (0) should be entered if the stream does not connect to this node. Repeat this procedure for all other unit operations (nodes) in the flowsheet.
6. After entering all of the information that describes your flowsheet, check the far right column. Each stream should now be identified as either FEED (stream that enters the flowsheet), PRODUCT (stream that exits the flowsheet) or INTERNAL (stream that remains internal to the flowsheet). If these labels do not agree with your flowsheet layout, you have incorrectly entered some of your data in the matrix area. To assist you in finding errors, the two rows have been provided at the bottom of the matrix area labeled JUNCTION and SEPARATOR. The numerical values in these rows tell you how many junctions (two streams in – one stream out) or separators (one stream in – two streams out) are present in your flowsheet for each node. A summary

of the stream data is also provided at the bottom of the page.

Step III – Enter the Experimental Mass and Assay Data

1. Select the **DATA** page of the spreadsheet by clicking on the appropriate tab at the bottom of the page. This is the page where you will enter the numerical data (mass flow rates and assays) that describe each stream in your flowsheet.
2. Please note that you do not need to re-enter a description of your circuit in the area titled CIRCUIT (Row 6). This is performed automatically.
3. Enter the names of the assays (e.g., copper, lead, zinc, ash, Btu/lb, sulfur, etc.) you have performed for each stream beneath the MEASURED VALUES title bar (Row 9). Note that the first entry cell has already been reserved for entering MASS. You may use up to 5 assay values to describe each stream.
4. Under the cell titled MASS, enter the mass flow rates for each stream. These values may be entered as a true flow rate (e.g., kg/min, tons/hr, etc.), as a measured quantity (e.g., gms, kgs, lbs, etc.) or as a relative percentage or fraction of the circuit feed. However, all values must be entered under the same format.
5. The numerical values for each assay must now be entered in the matrix beneath the assay names you entered

earlier. Normally, these values must be entered either as a relative indicator of mass or heat contained in each stream (e.g., % Cu, % ash, ppm Pb, Btu/lb, etc.). Note that percent solids is not appropriate as an assay value. Repeat this procedure for all streams in the flowsheet.

Step IV - Enter the Relative Standard Errors

1. Select the **ERRORS** page of the spreadsheet by clicking on the appropriate tab at the bottom of the page. This is the page where you will enter the relative errors for the experimental values pertaining to your flowsheet.
2. Once again note that you do not need to re-enter a description of your circuit in the area titled CIRCUIT (Row 6). This is performed automatically.
3. Enter the relative standard deviations (reported as percentages) for each experimentally measured (or estimated) value. If these values are not known, you may normally assume that assays were measured with a relative standard deviation of 1% and mass flow rates with a relative standard deviation of 10%. Any mass or assay value that was not known when entered on the DATA page should have the maximum relative standard deviation (i.e., 99%).

Step V - Initiate the Minimization Routine

1. Return to the **DATA** page of the spreadsheet by clicking on the appropriate tab at the bottom of the page.
2. The minimization routine will run more quickly if you provide the spreadsheet with initial guesses for the various experimental values. To achieve this, simply highlight all of the mass and assay values, click the right mouse button and select “copy”. Now highlight the same area beneath the ESTIMATED VALUES title bar (located to the right), click the right mouse button and select “paste”. If performed correctly, the total weighted sum-of-squares (WSSQ) at the right-bottom corner of the spreadsheet should be zero.
3. Now bring down the list of spreadsheet tools by selecting the “Tools” menu on the master header for the Excel spreadsheet. Under this list, you should select the equation solver subroutine by clicking the item labeled “Solver”. If you do not see the “Solver” option listed, then you probably did not specify that this option be loaded when you originally installed Excel. (“Solver” is not one of the default programs that is automatically loaded when you install Excel.) You should refer to the “Help” menu on the master header to obtain a step-by-step procedure for installing “Solver”.
4. Examine the entry titled SET TARGET CELL in the “Solver” dialog box. This value should be listed as \$M\$30. This is the cell that refers to the total

weighted sum-of-squares at the bottom-right corner of the spreadsheet. If this cell is not already selected, please do so now.

5. Examine the entry titled EQUAL TO in the “Solver” dialog box. The minimization option labeled MIN should be selected.
6. Examine the entry titled BY CHANGING CELLS in the “Solver” dialog box. Use the mouse to highlight this row. The range of cells specified in this entry should correspond to the matrix of estimated values (mass and assays) beneath the ESTIMATED VALUES title bar. All of the values that you plan to adjust should be highlighted.
7. Examine the entry titled SUBJECT TO THE CONSTRAINTS in the “Solver” dialog box. The constraints should be: $\$B\$39:\$K\$44=0$. If this is incorrect, click on the ADD or CHANGE button and modify the constraint to set cells within this range to zero. These cells are hidden on the **DATA** page, but refer to important calculations on the **WSSQ** page.
8. Click on the SOLVE button to begin the minimization process. This may take a considerable amount of time depending on the size and complexity of your flowsheet.
9. Once “Solver” finds a solution, select the OK button to accept the solution. The best estimates of your mass and assay values are now located beneath

the ESTIMATED VALUES title bar. These values represent a consistent and unambiguous set of flowsheet data.

Step VI – Evaluate the Minimization Results

1. If your data required a significant amount of adjustment, then one or more of the values in your original data were probably unreliable.
2. The amount of adjustment can be qualitatively observed by visually comparing the your original data (MEASURED VALUES) with the adjusted values (ESTIMATED VALUES). Alternatively, you may examine the calculated relative change between the measured and estimated values. These values are provided on the ERRORS page under the RELATIVE CHANGE IN MEASURED VALUE (%) title bar. A small value indicates that little adjustment was required, while a large value indicates that a large adjustment was required. A zero indicates no adjustment occurred.
3. A relative change of less than 10% can normally be accepted for data collected under typical plant conditions. Values requiring a larger adjustment should be examined for reliability.
4. You may wish to see if a better fit can be obtained by selecting different relative errors for the various streams. This is normally a trial-and-error approach that requires a significant degree of experience.

Mass Balance Example

The utility of the Techbal spreadsheet is best illustrated using an actual example. Consider the flowsheet shown in Figure 1 for a combination coal cleaning circuit incorporating spirals and froth flotation. Field data obtained using the flowsheet are summarized in Table 1.

Step I – Load Software

Activate the Microsoft Excel application and load the Techbal spreadsheet. The blank connection matrix page should appear. In order to avoid losing the master copy of the program, you should save the spreadsheet under a different file name. Remember that the only areas on the spreadsheet where data may be entered are colored grey. Values entered by the user will appear in blue text.

Step II - Enter the Flowsheet Connection Matrix

Select the **MATRIX** page of the spreadsheet by clicking on the appropriate tab at the bottom of the page. Enter a description of your circuit (Row 6), the names of the unit operations (Row 9), and the names of all streams that connect the operations (Column A). Within the matrix defined by the nodes and streams, enter a -1 or +1 to indicate whether each stream exits or enters each unit operation (node). The value zero (0) should be entered if the stream does not connect to this node. A completed copy of the **MATRIX** page for this example is shown in Figure 2.

After describing the flowsheet, check the far right column. Each stream should now be identified as either FEED (stream that enters the flowsheet), PRODUCT (stream that exits the flowsheet) or INTERNAL (stream that remains internal to the flowsheet). Two rows have been provided at the bottom of the matrix area labeled JUNCTION and SEPARATOR. The numerical values in these rows tell you how many junctions (two streams in – one stream out) or separators (one stream in – two streams out) are present in your flowsheet. For the case shown, there are four product (leaving) streams and five internal streams in addition to the single feed stream. All of the unit operations (cyclone, spiral, screen and flotation cell) are correctly identified as separators, while the sump is properly identified as a junction. If these labels do not agree with your circuit layout, you have incorrectly entered some of your data in the connection matrix area.

Step III – Enter the Experimental Mass and Assay Data

Select the **DATA** page of the spreadsheet by clicking on the appropriate tab at the bottom of the page. Enter the names of the assays (e.g., ash and sulfur) for each stream (Row 9) as well as the numerical values for the assays for each stream. Next, under the cell titled MASS, enter the mass flow rates for each stream. A completed copy of the **DATA** page for this example is shown in Figure 3.

Step IV - Enter the Relative Standard Errors

Select the **ERRORS** page of the spreadsheet by clicking on the appropriate tab at the bottom of the page. Enter the relative standard deviations (reported as percentages) for each experimentally measured (or estimated) value. If these values are not known, you may normally assume that assays were measured with a relative standard deviation of 1% and mass flow rates with a relative standard deviation of 10%. The higher the value, the less confidence you have in the measured value.

A large error (e.g., 99%) may be entered for an unknown value and small error (e.g., 0.001%) for values you wish to remain unchanged. A completed copy of the **ERROR** page for this example is shown in Figure 4.

Step V - Initiate the Minimization Routine

Return to the **DATA** page of the spreadsheet by clicking on the appropriate tab at the bottom of the page. The minimization routine will run more quickly if you provide the spreadsheet with initial guesses for the various experimental values.

To achieve this, simply highlight all of the mass and assay values, click the right mouse button and select “copy”. Now highlight the same area beneath the ESTIMATED VALUES title bar (located to the right), click the right mouse button and select “paste”. If performed correctly, the total weighted sum-of-squares (WSSQ) at the right-bottom corner of the spreadsheet should be equal to zero. The spreadsheet should now appear as shown in Figure 5.

Drop down the list of spreadsheet tools by selecting the “Tools” menu on the master header for the Excel spreadsheet. Select the equation solver subroutine by clicking the item labeled “Solver”. The dialog box shown in Figure 6 should appear. Examine the entry titled BY CHANGING CELLS. Use the mouse to highlight this row. The range of cells specified in this entry should correspond to the matrix of estimated values (mass and assays) beneath the ESTIMATED VALUES title bar. All of the values that you plan to adjust should be highlighted. After selecting the appropriate values, click on the SOLVE button to begin the minimization process. After “Solver” finds a solution, select the OK button to accept the solution. The best estimates of your mass and assay values are now located beneath the ESTIMATED VALUES title bar. The spreadsheet should now appear as shown in Figure 7.

Step VI – Evaluate the Minimization Results

If your data required a significant amount of adjustment, then one or more of the values in your original data were probably unreliable or collected under conditions that were not steady-state. The amount of adjustment can be qualitatively observed by examining the calculated relative change between the measured and estimated values. These values are provided on the **ERRORS** page under the RELATIVE CHANGE IN MEASURED VALUE (%) title bar. A relative change of less than 10% can normally be accepted for data collected under typical plant conditions. However, the required accuracy may vary greatly depending on the

intended use of the data. For the example shown, the adjustments were all less than about 5%, suggesting that this was a relatively reliable data set.

You may wish to see if a better fit can be obtained by selecting different relative errors for the various streams. This is normally a trial-and-error approach that requires considerable experience.

Problems?

If you have technical questions related to the operation or application of the Techbal spreadsheet, please contact:

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User Information

Techbal may be freely distributed by commercial or educational organizations provided that the primary calculation cells remain unaltered. The authors provide no warranty related to the correctness or applicability of the spreadsheet and assume no liability for user decisions that may be based on the spreadsheet output. Microsoft Excel[®] is a registered trademark of the Microsoft Corporation. The use of Excel should not imply an endorsement by the author.

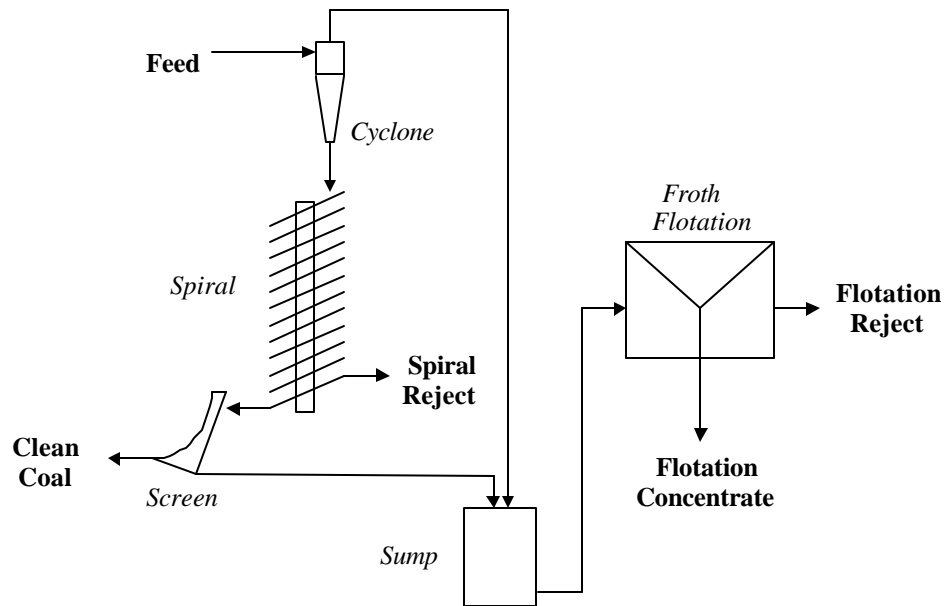


Figure 1. Example of a typical spiral-flotation coal cleaning circuit.

Table 1. Field data obtained for the spiral-flotation coal cleaning circuit.

Stream	Rate (tph)	Ash (%)	Sulfur (%)
Circuit Feed	149.0	27.90	0.89
Cyclone Oversize	112.0	26.10	0.71
Cyclone Undersize	37.0	33.50	1.33
Spiral Concentrate	83.0	8.60	0.56
Spiral Reject	28.0	76.20	1.21
Screen Oversize	78.0	7.81	0.55
Screen Undersize	4.9	21.40	0.71
Flotation Feed	42.0	32.20	1.25
Flotation Concentrate	26.0	8.10	0.86
Flotation Reject	15.9	71.80	1.71

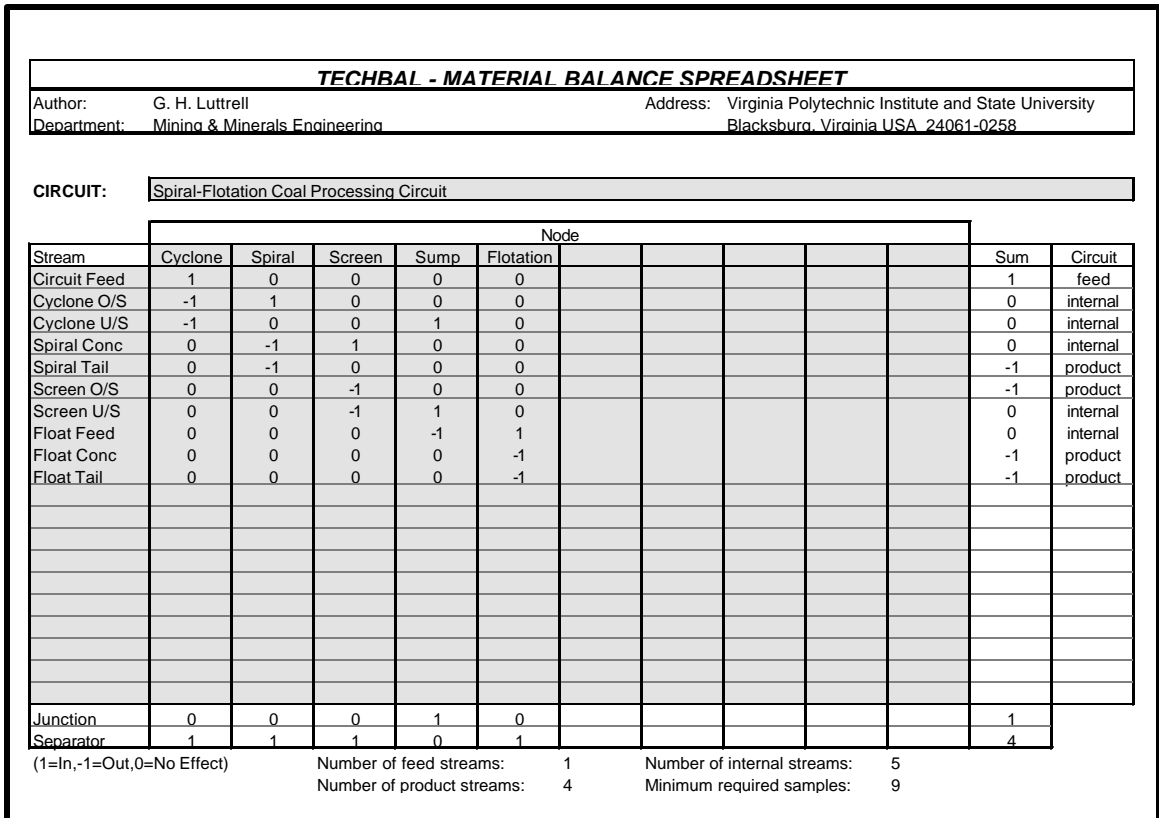


Figure 2. Completed MATRIX page describing the plant flowsheet.

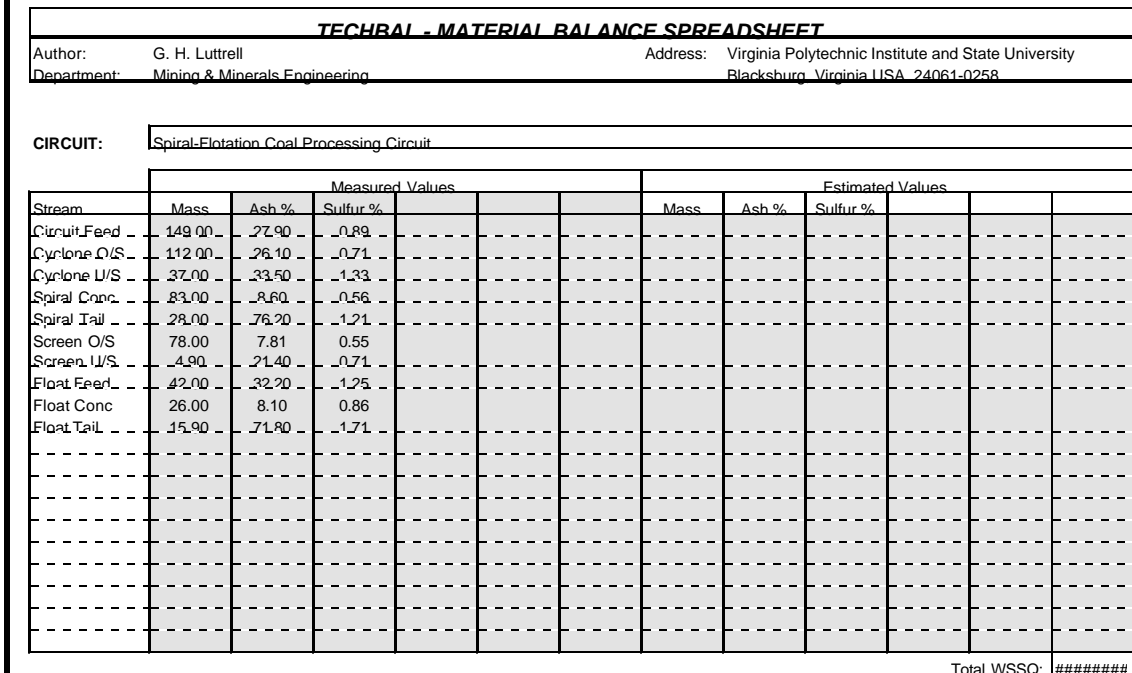


Figure 3. Completed DATA page showing measured mass and assay values.

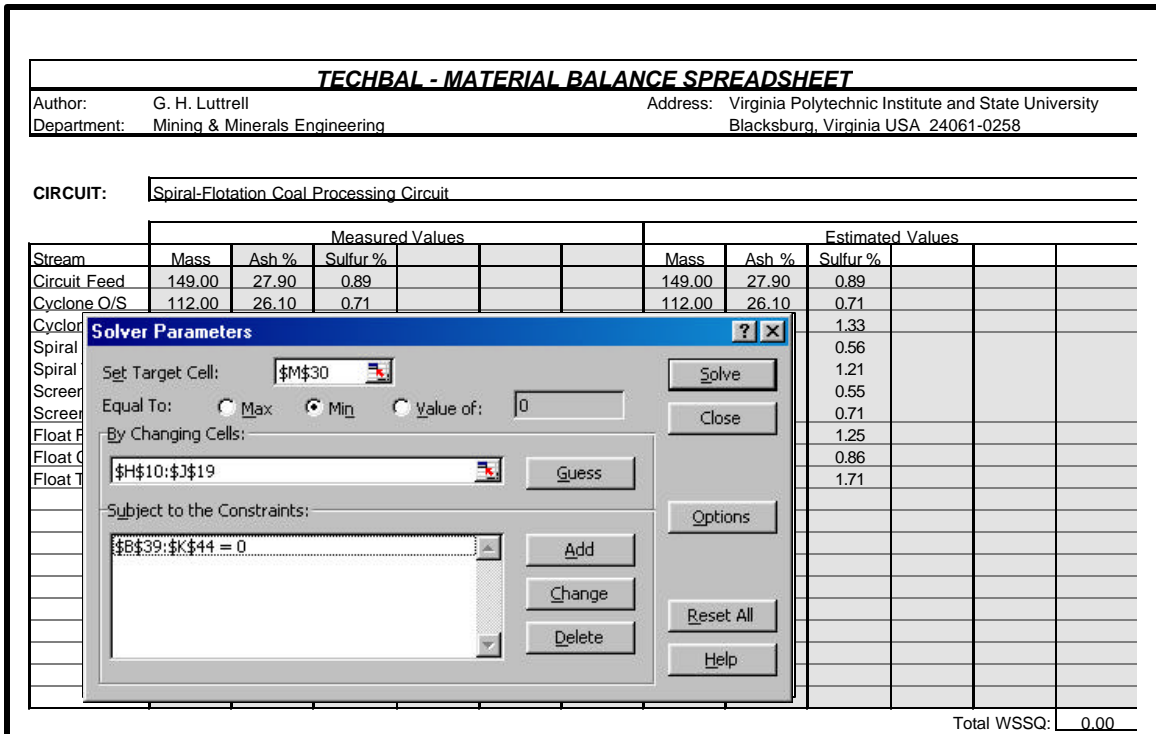


Figure 6. DATA page just prior to starting the Solver search routine.

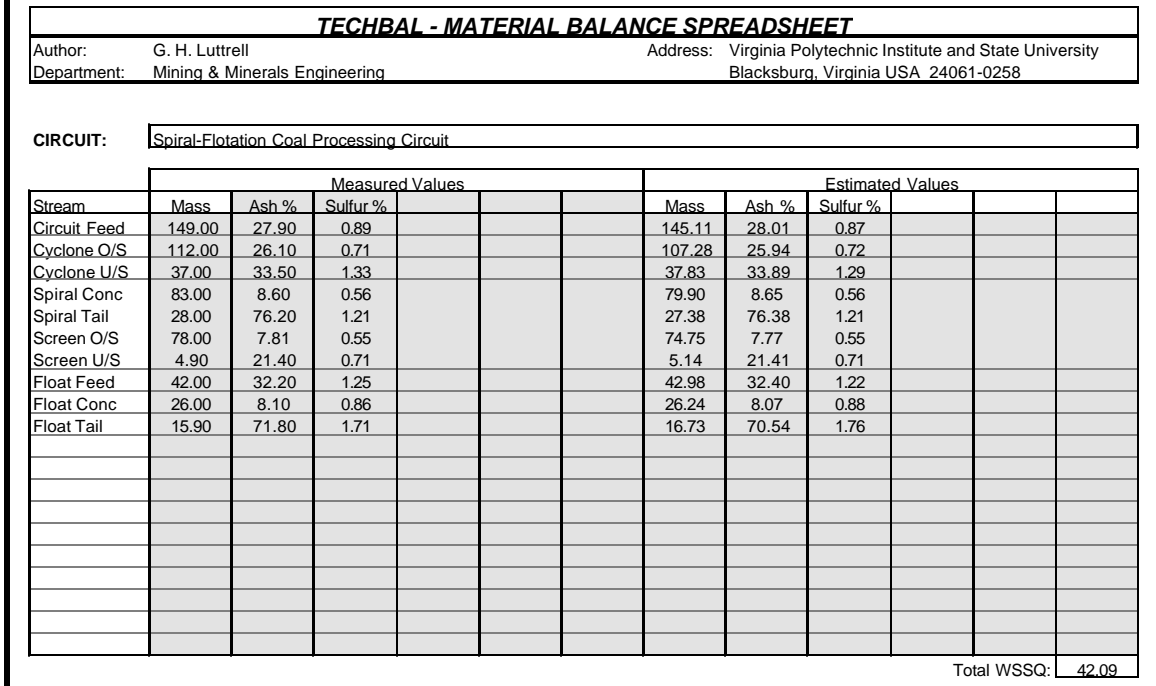


Figure 7. DATA page after solving for estimated values.

