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### 51. Mass Balance Module



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### 51.1. Where do we need mass balancing?

Mass balancing is a common practice in metallurgy. The mass balance of a circuit is needed for several reasons:

- 1. To estimate the metallurgical performance of the circuit
- 2. To locate process bottlenecks and for circuit diagnosis
- 3. To create models of the processing stages
- 4. To simulate the process.

The following steps are often required to simulate a process:

- 1. Collecting experimental data (experimental work, sampling, sample preparation, assaying)
- 2. Mass balancing and data reconciliation of the experimental data
- 3. Model building
- 4. Simulation.

In HSC Chemistry® 8, you can do all the steps in one program: *HSC Sim* with the *Mass Balance* tool. The work flow in the HSC Sim and Mass Balance tool starts from a flowsheet drawing, followed by importing experimental data, performing mass balancing, model fitting & building (model fitting will be available later on) and simulation (**Fig. 1**).



Fig. 1. From flowsheet with data through mass balancing to modeling and simulation.



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### 51.2. Mass balancing capabilities in HSC Chemistry® 8

HSC 8 allows the user to solve the following mass balance problems (**Table 1**). There are three different possibilities for the solution:

- Solids
- Assays only
- Solids and water independently

Liquid flow rates and %solids are solved only if Solve solids and water independently is chosen. If Assays only is chosen, there must be a Total solids measurements for all the flows to be balanced.

- 1. Unsized
  - Balance Total Solids flow rates. At least one total solids flow rate measurement must be given
  - Balance Total Water/liquid flow rate. This is done by first balancing the Total solids flow rates and after that the Total Water/liquid flow rate independently
  - Balance %solids
  - Balance Solids component assays/Mineral assay. At least one solids component assay or mineral assay must exist
- 2. Sized
  - Balance Total Solids flow rates for bulk and all the size fractions. At least one total solids flow rate measurement for bulk must be given
  - Balance size fraction wt-% for size fractions
  - Balance Total Water/liquid flow rate for bulk. This is done by first balancing the Total solids flow rates and after that Total Water/liquid flow rate independently
  - Balance %solids for bulk
  - Balance Solids component assays/Mineral assay for bulk. If no solids component assays/mineral assays exist, the solids component assays/mineral assays for bulk are not balanced
- 3. Sized by assay
  - Balance Total Solids/Slurry flow rates for bulk and all the size fractions. At least one total solids/slurry flow rate measurement must be given
  - Balance size fraction wt-% for size fractions
  - Balance Total Water/liquid flow rate for bulk. This is done by first balancing the Total solids flow rates and after that Total Water/liquid flow rate independently
  - Balance %solids for bulk
  - Balance Solids component assays/Mineral assay for bulk and the size fractions

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Measured or	Unsized	Sized	Sized by Assays
estimated values	Components		
Total solids flow rates	Х	Х	Х
Water/Liquid flow rates	Х	Х	Х
Solids component Assay/Mineral Assay bulk	Х	Х	Х
Solid Component Assays/Mineral assays Size Fractions	Х		Х
%Solids	Х	Х	Х
Fraction m%		Х	Х
Total Solids Flow rate size fractions		Х	Х

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### 51.3. Overview of the HSC Sim 8 Mass Balancing tool

The HSC Mass Balance tool is started from the HSC 8 Main Menu dialog or from HSC Sim Menu: Tools  $\rightarrow$  Mass Balance. The window layout consists of: Balancing Navigator, Working Area, Property Panel, and Upper Buttons.

		Upper Buttons:			
	HSC S	Sim 8 - Mass Balance			
Balancing Navigator:		Breast Backup Invest	(?)		
Balancing Navigator 🛛	and Close	e and Close THSC7 Data ReX Data Errors	-		
Experimental Data ^		Main Menu			
<u>Units</u> Streams	HSC Sim 8 - Mass Balance	*		- D X	
Variables Size Fractions Data Sets	Update Discard Backup and Close and Close + H	Incot Incot Creck for Heb COTAble Creck for Heb			Property Panel:
Measurement Data	Balancing Navigator #	Selected Unit Name	<ul> <li>PSD Changing</li> </ul>	Properties #	Properties #
🕑 Data Status 🔷	Lines Augusta	St Gener      Znd Cleaner      Ordone		Vinit A Name 1st Cleaner PSD Changing	Unit A
Stream View Variable View	Streams Variables Size Fractions Data Sets	Process Waters     Rougher     SAG		Selected V	PSD Changing Selected
Standard Deviations	Measurement Data	M Scavenger			
SD - Stream View SD - Variable View	Stream View Variable View				
	Standard Deviations ^	Working Area			
Balancing ^	SD - Stream View SD - Variable View				
Calculate Compare	Land Balancing ^				
Reporting ^	Compare				
Results	Results				
	@2014 Outotec Oyj				

#### Fig. 2. Main components of the Mass Balance window.

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### 51.4. Step-by-step example: data reconciliation and mass balancing in HSC 8

This step-by-step example shows how to do mass balancing for unsized data, consisting of the solids flow rates and assayed element (Cu, Ni, S) for a rougher-scavenger flotation bank. The work starts from HSC Sim 8 by drawing the process flowsheet. The Mass Balance tool is started from the HSC Sim Tools menu. The steps to import the data and to balance it follow the left side <u>Balancing Navigator</u> panel (**Fig. 2**) from top to bottom. More examples are found in Chapter 52.

### 51.4.1. Drawing the flowsheet

First the flowsheet is prepared in HSC Sim 8. In this rougher-scavenger flotation example it looks as shown in **Fig. 3**.

You can draw all the streams and units. HSC will create the mass balance equations according to the available data; therefore, there is no need to draw a flowsheet for mass balancing only or a new flowsheet every time for different kinds of mass balance problems.

When naming the streams, use identical names to those in your analysis lists. Before proceeding, please check the stream connections and check the flowsheet for possible errors.



Fig. 3. HSC Sim flowsheet drawing of a flotation process with rougher and scavenger cells.

### 51.4.2. Importing the experimental data

When the flowsheet is ready (i.e. all streams are named properly and connections have been checked), you can import your experimental data. The following subsections will concentrate on how to import the data for mass balancing and data reconciliation.

### 1. Select units

The units are listed based on the flowsheet drawing figure, but they cannot be edited here. In this view you can:

- Select or deselect the units to be included in the balancing calculation.
- Set whether the unit will change the particle size distribution of the solids, e.g. grinding mills. This selection is needed in sized balancing, to indicate that the fraction balance will not be held over those units.

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7 npo	rt Import ReX Data	Check for Help		
lain	Menu			
S	elected	Unit Name	PSD Changing	İ
	$\checkmark$	1st Cleaner		
	$\checkmark$	2nd Cleaner		
	$\checkmark$	Cyclone		
	$\checkmark$	Process Waters		
	$\checkmark$	Rougher		
	$\checkmark$	SAG	$\checkmark$	
	$\checkmark$	Scavenger		

Fig. 4. Experimental Data – Units.

### 2. Select streams

The streams are listed based on the flowsheet drawing figure, but they cannot be edited here.

Here you can:

- Select and deselect the streams to be included in the balancing calculation.
- Change the stream type:
  - o Unknown
  - o Solids/Slurry
  - o Liquid/Water

By default it is unknown, since the data has not yet been imported. When importing the data, the type is detected by pressing Detect stream types, but it can be changed here.

Selecte	d Type	Stream Name 🔺	Source	Destination
	Unknown	Conditioned	Conditioner	Rougher 1
$\checkmark$	Unknown	Feed	?	Conditioner
$\checkmark$	Unknown	Final Tails	Scavenger 4	?
$\checkmark$	Unknown	R1Conc	Rougher 1	Rgh Conc Sump
$\checkmark$	Unknown	R 1Tails	Rougher 1	Rougher 2
$\checkmark$	Unknown	R2Conc	Rougher 2	Rgh Conc Sump
$\checkmark$	Unknown	R2Tails	Rougher 2	Scavenger 1
V	Unknown	Rgh Concentrate	Rgh Conc Sump	?
$\checkmark$	Unknown	RS1Conc	Scavenger 1	Scav Conc Sump
$\checkmark$	Unknown	RS1Tails	Scavenger 1	Scavenger 2
$\checkmark$	Unknown	RS2Conc	Scavenger 2	Scav Conc Sump
$\checkmark$	Unknown	RS2Tails	Scavenger 2	Scavenger 3
$\checkmark$	Unknown	RS3Conc	Scavenger 3	Scav Conc Sump
V	Unknown	RS3Tails	Scavenger 3	Scavenger 4
$\checkmark$	Unknown	RS4Conc	Scavenger 4	Scav Conc Sump
V	Unknown	Scav Concentrate	Scav Conc Sump	?

Fig. 5. Experimental Data – Streams.

### 3. Add variables

Next, the measured variables are added / removed from the upper bar buttons. The variable name and unit on the list can be edited, and the variable can also be unselected from balancing if desired. The variable types are listed in **Table 2**.

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HSC Sim 8 - Mass Balance **B** G 2 DX X 7 Update Discard Import Check for Help Add Elements... Add Mineral Add Variable Remove Backup Import and Close and Close HSC7 Data ReX Data from DB... Variable Errors Main Menu Variables **Balancing Navigator** 4 Selected Variable Name Meas. Unit Type Abbreviatio  $\checkmark$ Total solids SE t/h Total Solids Experimental Data ~ 1 % Cu Solids Component Assay A  $\checkmark$ Fe % Solids Component Assay A Units 1 S % A Solids Component Assay Streams Variables Size Fractions Data Sets Measurement Data

Fig. 6. Experimental Data – Variables.

Table 2.	Data	types	of	the	variables.

Data type	Abbreviation	Examples
Total solids flow rate	SF	Total t/h, g
Solids component flow rate	SC	Iron t/h, plastic t/h, g
Solids component assay	A	Cu%, P2O5%
Mineral assay	М	Ccp%, Py%, Qtz%
Size Fraction wt %	SA	0-20um %, 20-45um %
Solids percentage	SP	35%
Not included	NA	Column with comments, extra data (temperature), etc.

### 4. Add size fractions

By default, one size fraction exists: 'Bulk', which cannot be removed. More size fractions can be added to /removed from the list by clicking the buttons on the upper bar. Fraction names can be given.



Fig. 7. Experimental Data – Size Fractions.

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### 5. Add dataset(s)

By default, one dataset exists, which can be renamed here. In addition, more datasets can be added and selected one at a time to carry out data reconciliation.

<b>N</b>	
Add Data Set	Remove Data Set
Data	Sets

Fig. 8. Experimental Data – Datasets.

### 6. Import measurement data

In this view, a stream variable template is automatically generated and displayed. The data can be entered by:

- a) Typing manually in the table
- b) Copying an empty data template → organizing the data e.g. in Excel → select 'Paste Experimental Data'. This will automatically place the data in the correct rows and columns based on the clipboard table content. Note: if the data is horizontal (stream names in rows) there must exist a column labelled Fraction that contains fraction names. If the data is vertical (stream names in columns) there must exist a row labelled Fraction containing the fraction names.
- c) Importing the old HSC7 Analyses.xls mass balance file

Each dataset is presented in a separate table tab.

Mas HSC Sim 8 - Mass B	alance											
Undate Discard	Backup	7		Check for			Paste			View Mineral	%∕∕	Back C
and Close and Close	*	HSC7 D	ata ReX Data	Errors	* The Tool	<ul> <li>Expe</li> </ul>	rimental D	ata	Mineral	Matrix	Water	Missing
		Main	Menu			Table					Data	Tools
Balancing Navigator	ą		A	В	С	D	E	F	G	н	1	
*		1	Stream	Fraction	Fraction m%	Total Solids t/h	Cu %	Fe %	5%			
Experimental Data	^	2	ROM	Bulk		112.000	1.004	6.096	5 7.000			
		3	ROM	0-20 um	1.000		1.004	6.096	5 7.000			
Units		4	ROM	20-37 um	2.000		1.004	6.096	5 7.000			E
Streams		5	ROM	37-74 um	5.000		1.004	6.096	5 7.000			
Variables		6	ROM	74-106 um	12.000		1.004	6.096	5 7.000			
Size Fractions		7	ROM	106-250 un	n 80.000		1.004	6.096	5 7.000			
Data Sets		8	SAG Discharge	Bulk		370.612	1.004	6.096	5 7.000			
Measurement Data		9	SAG Discharge	0-20 um	15.049		1.004	6.096	5 7.000			
		10	SAG Discharge	20-37 um	9.654		1.004	6.096	5 7.000			
🛛 Data Status	~	11	SAG Discharge	37-74 um	16.405		1.004	6.096	5 7.000			
		12	SAG Discharge	74-106 um	10.780		1.004	6.096	5 7.000			
Stream View		13	SAG Discharge	106-250 un	48.112		1.004	6.096	5 7.000			
Variable View		14	Cyclone UF	Bulk		258.612	1.004	6.096	5 7.000			
		10	C 1	0.00	1 100		4 004	r	7 000			

Fig. 9. Experimental Data – Measurement Data.

### 51.4.3. Reviewing and complementing the data

In this part, the idea is to inspect the data and get an understanding of what values will be available after balancing. Also, the data status before balancing is reviewed here and can be changed. Thus changes are reflected in the status after balancing.



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### The status indications are:

- Stream:
  - · Missing: no data
  - Complete: all variables have data
  - Partial: some variables have data

#### Variable:

- Missing: no data
- Measured: data existing
- Guesstimated: data are a user-given guesstimation; high uncertainty is set automatically for this The guesstimation is given in the property **User value**
- Fixed: the user sets including the value that you do not wish to change during the balancing. However, the fixed value may change during balancing because the fixing is done by setting the uncertainty to small. The fixed value is given in the property **User value**
- By Equation: stream total solids can be set to be a multiple of another stream
- Excluded: data will not be included in the calculation
- After Balancing:
  - Balanced: solved using data reconciliation
  - Calculated: calculated based on unit material balance
  - Non Available: data are also missing after balancing

The status indications can be changed by clicking the data table cell (dropdown menu) or from the property panel on the right.

The balance equations for the units can be reviewed by clicking the upper bar button shown.



Equation <ul> <li>SAG Discharge = Cyclone OF</li> <li>Cyclone OF = RC + RT</li> <li>RC + SC + CT2 = CC1 + CT1</li> <li>CC1 = Final Concentrate + CT2</li> </ul>	М	iss Balance Equations X
<ul> <li>★ SAG Discharge = Cyclone OF</li> <li>★ Cyclone OF = RC + RT</li> <li>★ RC + SC + CT2 = CC1 + CT1</li> <li>★ CC1 = Final Concentrate + CT2</li> </ul>		Equation
Cyclone OF = RC + RT     RC + SC + CT2 = CC1 + CT1     CC1 = Final Concentrate + CT2		
<ul> <li>              RC + SC + CT2 = CC1 + CT1      </li> <li>             CC1 = Final Concentrate + CT2         </li> </ul>		E Cydone OF = RC + RT
CC1 = Final Concentrate + CT2		$ \blacksquare RC + SC + CT2 = CC1 + CT1 $
T + CT1 = SC + Final Tail		⊞ RT + CT1 = SC + Final Tail
		Copy to Clipboard Close

Fig. 10. Opening and reviewing the balance equations.



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#### 1. View by streams

The data are presented in a pivot table where the <u>stream</u> is the major column. The data status is shown in pie charts.



Fig. 11. Data Status - Stream View

#### 2. View by variables

The data is presented in a pivot table where the <u>variable</u> is the major column. The data status is shown in pie charts.

			Dataset 🔺		
			Circuit_Sampling_	on_January	ann
Variable 🔺	Stream 🔺	Fraction 🔻	Value	Value Status	Balanced Value
+ Cu %	+ Conditioned	Bulk		Missing	Non Available
	✓ Feed	Bulk	0.45	Measured	Balanced
		Bulk	0.08	Measured	Balanced
		Bulk	20.75	Measured	Balanced
	* R1Tails	Bulk	0.24	-	Balanced
		Bulk	17.12	Missing	Balanced
		Bulk	0.15	Guesstimated	Balanced
	✓ Rgh Concent	Bulk		Excluded	Non Available
		Bulk	14.00	Measured	Balanced
		Bulk	0.12	Measured	Balanced
	- PS2Copc	Bulk	12 35	Measured	Balanced

Fig. 12. Data Status - Stream View.

### 51.4.4. Setting the measurement accuracies

Each assay and piece of raw data is subject to errors. Mass balancing and data reconciliation is meant for adjusting unreliable values, whereas reliable values should be adjusted only a little, if at all. Therefore, the user has to give a value of how reliable each item of raw data is. This is done by defining the error model to give a <u>standard deviation</u> value for the measurement data.

In the HSC Sim 8 Mass Balance tool, the standard deviation can be given using userfriendly pre-settings for the error models.



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### To define the standard deviations you need to select:

Table 3. Descriptions of error model functions.

Error Model	Parameters	Example
Fixed	Fixed standard deviation as a plain number or fixed relative standard deviation as a negative number or in	0.1
	parentheses	-5, (5)
X.x = X%+0.x	The integer is the relative standard deviation; the decimal is the detection limit	10.1
X%+0.1	Given parameter is the relative standard deviation; 0.1 is the detection limit	6
10%+X	Parameter is the detection limit; relative standard deviation is fixed at 10%	0.05
a;b;c = MIN(a%+b;c)	a is the relative standard deviation, b is the detection limit, and c is the maximum standard deviation	10;0.01;0.5
a;b;c=MAX(a%+b;c)	a is the relative standard deviation, b is the detection limit, and c is the minimum standard deviation	10;0.02;0.2
a;b;c=%;MIN;MAX	a is the relative standard deviation, MIN is the minimum standard deviation, and MAX is the maximum standard deviation	10;
Manual	Standard deviation is given in the data individually for each stream	

### 1. Standard deviations by streams

The data are presented in a pivot table where the <u>stream</u> is the major column. Standard deviation settings of all variables for that stream can be easily set at once.

HSC Sim 8 - Mass Balance													
Update Discard and Close Backup	Import HSC7 Da	Impr ta ReX E	ort Check for Errors	() Help									
Balancing Navigator 4					Dataset 🔺					1	Pro	perties	
					Dataset 1						5	Stream	
Experimental Data 🔷	Strea	m 🔺	Variable 🔺	Fraction -	Measuremen	t Method	Value	PSD-%	SD			Name	CT1
10.00			0. N	p.d.	Medsuremen	his-MIN(28/ ibic)	value	K3D-76	30 0.0	U		Source	1st Cleaner
Units	U + CC	1	↓ Cu %	DUIK	a,			0.0	0.0			Destination	Scavenger
Streams			✓ Fe %	Bulk	a;b;c=MIN(a%+b;c)			0.0	0.0		5	Sampling of Stream	
Variables			≠ S %	Bulk	a;	b;c=MIN(a%+b;c)		0.0	0.0			Measurement M	etho a;b;c=MIN(a%+b;c)
Size Fractions				Bulk	a;	b;c=MIN(a%+b;c)		0.0	0.0			x	0
Data Sets	- CT	1	✓ Cu %	Bulk	a;b;c	=MIN(a%+b;c) 🔻		0.0	0.0			X	0
Measurement Data				Bulk	a;	b;c=MIN(a%+b;c)	2	0.0	0.0			a	5
Data Statur			× 5 %	Bulk	a:	h:c=MIN(a%+h:c)		0.0	0.0			b	0.1
			Tabel salida bila	Dull	3)	his=MIN(a% this)		0.0				с	0.5
Stream View			+ Total solius (/I	DUIK	a,	D,C-MIN(a /o+D,C)		0.0	0.0				
Variable View	- CT	2	▼ Cu %	Bulk	a;	b;c=MIN(a%+b;c)		0.0	0.0				

**Fig. 13.** Standard Deviations – SD – Stream View.

### 2. Standard deviations by variables

The data are presented in a pivot table where the <u>variable</u> is the major column. Standard deviation settings of all streams for that variable can be easily set at once.

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<ul> <li>Solution</li> <li>Solution&lt;</li></ul>	•	7 (	2		(?)							
Update Discard Bac and Close and Close "	kup F	Import In ISC7 Data Re	nport X Data	Check for Errors	Help							
Balancing Navigator	4						Dataset 🔺					1
Experimental Data	~	Europa La					Dataset1					
	-	Variable	Stre	am 🔺	Fraction	•	Measurement	t Method	Value	RSD-%	SD	
Units		Cu %	CT1		37-74 um	1	a;l	b;c=MIN(a%+b;c)	1.27	12.9	0.2	
Streams					20-37 um		a;l	b;c=MIN(a%+b;c)	1.20	13.3	0.2	
Variables					106-250	um	a;l	b;c=MIN(a%+b;c)	2.00	10.0	0.2	
Size Fractions					0-20 um		a;l	b;c=MIN(a%+b;c)	1.77	10.7	0.2	
Data Sets			+ C	T2	Bulk		a;l	b;c=MIN(a%+b;c)	2.91	8.4	0.2	
Measurement Data					74-106 ur	m	a;l	b;c=MIN(a%+b;c)	3.15	8.2	0.3	
Data Status	~				37-74 um		a;l	b;c=MIN(a%+b;c)	2.79	8.6	0.2	
	-				20-37 um		a;l	b;c=MIN(a%+b;c)	2.43	9.1	0.2	
Stream View					106-250	um	a;l	b;c=MIN(a%+b;c)	4.31	7.3	0.3	
Variable View					0-20 um		a;l	b;c=MIN(a%+b;c)	3.23	8.1	0.3	
Standard Deviations	~		+ C	ydone OF	Bulk		a;l	b;c=MIN(a%+b;c)	1.00	15.0	0.2	
TT	_		-	3	74 100			he-MINI(=0(+h.c)	1.00	15.0	0.2	

**Fig. 14.** Standard Deviations – SD – Variable View.

### 51.4.5. Mass balancing

In the mass balancing upper bar, the following can be selected:

- Sum = 100: if the mineral component sum is required to be 100%.
- Method: LS, NNLS, CLS
- Data to Balance: Assays only, Solids and assays, Solids and water
- PSD Balance: Unsized, Sized, Sized by Assay
- Calculate: runs the data reconciliation

The balancing results can be viewed graphically with, see Fig. 15:

- Balance Convergence
- Parity Chart

To solve a mass balance problem, the following mathematical methods are available in the Balance/Report Options on the right-hand side:

- Least Squares Solution (LS)
- Non-negative Least Squares Solution (NNLS)
- Constrained Least Squares Solution (CLS)

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			Dataset 🔺			1	/		1
Stream 🔺	Variable	Fraction -	Dataset1	P.L. Jul	D:66	n			
Sucan -			Value	Balanced Value	Diff	RelDiff	Min	Max	R.
(CI	* Cu %	34.105 um	11.11	11.11	0.0	0.00			-
		74-106 um	12,41	13.39	1.2	0.09			-
		37-7 <del>-</del> um	10.15	10.03	0.0	0.00			-
		106-250 um	14.40	16.21	1.0	0.01	-		-
	0-20 um		11.10	10.55	0.1	0.11	1		
	✓ Fe %	Bulk	41.25	41.25	0.1	0.01			
	+ 1 € 70	74-106 um	40.57	39.05	0.0	0.00		-	
		37-74 um	40.97	40.94	0.0	0.02	-		+
		20-37 um	41.65	41.62	0.0	0.00			-
		105 750 um	20 74	20 07	0.0	0.00			
Jalance Conve	rgence	ć	] 🗖 🖣 🛛 Parit	y Chart				0.	-
a					Datas	etl			
i i i i i i i i i i i i i i i i i i i					Duras				

Fig. 15. Balancing – Calculate.

Mass balance problems are solved in two stages: firstly, the total mass flow rates are solved and then the assays are reconciled. In solving the assays, the least squares solution finds the best solution by minimizing the weighted sum of squares, i.e.

$$WSSQ = \sum_{j=1}^{k} \sum_{i=1}^{n} \frac{(a_{ij} - b_{ij})^{2}}{s_{ij}^{2}}$$
(1)

where j refers to the stream, k is the number of streams, i refers to the components (analyses), n is the number of components, *a* is the measured value, *b* is the balanced value, and s is the standard deviation.

In non-negative least squares, all 'a's are subject to being non-negative.

In constrained least squares, all 'a's are subject to being between the min. and max.

By clicking dataset you can see the solution parameters Balance tolerance, Max iter and Estimate of null SD in the properties window. Balance tolerance is the condition that defines when the iterations stop and Max iter is the maximum number of iterations. If you don't get reasonable balance you can try to change Estimate of null SD greater.

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### 51.4.6. Reporting and reviewing the results

HSC Sim 8 - Mass Balance								
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Balancing Navigator 4		A	В		c	D	E	F
*	1	Streams	Fraction name	<b>Total Solid</b>	s t/h Meas. T	otal Solids t/h Bal.	Cu % Meas.	Cu % Bal.
Units	2	ROM	Bulk		215.000	215.000	0.890	0.872
Streams	3	SAG Discha	Bulk					
Variables	4	Cyclone UF	Bulk					
Size Fractions	5	Cyclone OF	Bulk					
Data Sets	6	RC	Bulk					
Measurement Data	7	CC1	Bulk					
	8	<b>Final Conce</b>	Bulk			6.076	26.100	26.101
🗗 Data Status 🔷	9	RT	Bulk					
	10	SC	Bulk					
Stream View	11	Final Tail	Bulk			208.924	0.120	0.138
Variable View	12	CT2	Bulk					
L	13	CT1	Bulk					
Standard Deviations	14	Mill Water	Bulk					
CD Stroom View	15	Mill Sump \	Bulk					
SU - SU Editi VIEW	16							

Fig. 16. Stream Summary

	А	В	С	D	E	F
1	Variable	wssq	DiffTot	RelDif	AVG_SD	AVG_RSD
2	Total Solids t/h	0.000	0.000	0.000	0.500	0.002
3	Cu %	0.045	0.037	0.136	0.250	0.028
4	Fe %	6.681	1.556	6.429	0.450	0.056
5	S %	0.102	0.222	0.401	0.490	0.027
6						
7	Stream	Sum WSSQ	DiffSum	RelDiffSum	RelDiffAvg	
8	ROM	4.044	0.907	0.393	0.007	
9	SAG Discharge	0.000	0.000			
10	Cyclone UF	0.000	0.000			
11	Cyclone OF	0.000	0.000			
12	RC	0.000	0.000			
13	CC1	0.000	0.000			
14	Final Concentrate	0.002	0.026	0.033	0.019	
15	RT	0.000	0.000			
16	SC	0.000	0.000			
17	Final Tail	2.781	0.882	6.354	0.070	
18	CT2	0.000	0.000			
19	CT1	0.000	0.000			
20	Mill Water	0.000	0.000			
21	Mill Sump Water	0.000	0.000			
22						

Fig. 17. Reporting – Results: Goodness.

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	А	В	С	D	E	F	G	
1	Units	Equations	Stream	Total Solids	Cu %	Fe %	S %	
2	SAG + Cyclo	ROM = Fina	l Concentrat	te + Final Tai	il			
3		Inputs	ROM	215.000	1.874	14.142	17.653	
4		Outputs	<b>Final Conce</b>	6.076	1.586	0.679	2.418	
5			Final Tail	208.924	0.288	13.463	15.235	
6		Balance		0.00E+00	8.73E-13	-3.62E-11	-5.13E-12	
7								

Fig. 18. Reporting – Unit Balance.

### 51.4.7. Importing HSC7 Excel files

The Excel files to be imported may contain a sheet with flowsheet information (**Fig. 19**). If this sheet is named Flowsheet, the program automatically detects the sheet where the flowsheet information is located. If the name is something else or there is no sheet containing flowsheet information, the name must be specified (**Fig. 23**, Select Flowsheet)

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A1	<b>▼</b> (**	<i>f</i> <sub>∞</sub> Units									*
A	В	C	D	E	F	G	Н	1	J	K	L
1 Units	ROM	SAG Discharge	Cyclone UF	Cyclone Of	RC	CC1	Final Concentrate	RT	SC	Final Tail	CT2
2 SAG	1	-1	1	0	0	0	0	0	0	0	0
3 Cyclone	0	1	-1	-1	0	0	0	0	0	0	0
4 Rougher	0	0	0	1	-1	0	0	-1	0	0	0
5 1st Cleaner	0	0	0	0	1	-1	0	0	1	0	1 =
6 2nd Cleaner	0	0	0	0	0	1	-1	0	0	0	-1
7 Scavenger	0	0	0	0	0	0	0	1	-1	-1	0
8 Process Waters	s 0	0	0	0	0	0	0	0	0	0	0
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Ready	, - , ourre	, = A = Grinding					, X 0		1四 100% (-	)	( <del>+</del> )
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Fig. 19. An Excel sheet containing flowsheet data.

The measurement data is read from a different sheet of the same Excel file. The first column must be named Streams (Cell A1), the second Source (Cell A2), and the third Destination (cell A3) if the data are horizontal (**Fig. 21**). If the data are vertical, the first row must be named Streams (A1), the second row must be named Source (A2), and the third Destination (A3) (**Fig. 20**). Imported vertical data can only be unsized or sized (without analyses).

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	A	В	C	D	E	F	G	E
1	Stream->	ROM	SAG Discharge	Cyclone UF	Cyclone OF	Mill Water	Mill Sump Water	
2	Source	7	SAG	Cyclone	Cyclone	Process Waters	Process Waters	_
4	Mass%	SAG	Cyclone	SAG	Rougher	SAG	Cyclone	
5	Solids Flowrate t/h	517.5	1810	1290	517.5	0	0	
6	Water t/h	20	600	520	600	180	200	
7	%Solids	96.6	75.7	71.2	44.6	0	0	
8	Cu %	1.2	1.22	1.3	1.96	0	0	
9	S %	12.4	13.2	14.3	12.5	0	0	_
10	0-53um	9.7	18.6	11.1	35.9	0	0	
11	53-/50m	1.0	4.2	2.5	10.9	0	0	
12	150-300um	4.0	9.2	16.5	21.2	0	0	-
14	300-600um	6.8	19.7	23.2	13.5	0	0	-
15	600-850um	3.3	7.8	10.3	2.2	0	0	
16	850-1180um	4.5	5.3	7.2	1.2	0	0	
17	1180-2360um	9.4	6.6	9.6	0.7	0	0	_
18	2360-4750um	19.5	5.8	7	0	0	0	
19	4750-9500um	30.5	4.7	5.1	0	0	0	
20	9500-13200um	3.4	0.9	1	0	0	0	
21	13200-20000um	0.9	0.2	0	0	0	0	
14 .	Survey 1	Survey 2	3 Grinding Su	urvey 4 U	nsized Compon	ients 📈 4 1D Fu	lly Ball ◀ 💷 ► [	1
Rea	ady					🗆 🛄 100% 😑		) .:

Fig. 20. Vertical sized data (without analyses).

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aste 🕜 B I	<u>u</u> •	<u>≫ • A</u> • ■		-2- *	<b>9</b> • %	,	Conditiona Formatting	I Format Cell as Table + Styles +	Pormat	• 🛃	Sort & Fin Filter * Se	nd & lect •
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H7	- (* )	fx										
A	В	С	D		E	F	G	Н	1	J	K	L
Stream	Source	Destination	Solids Recovery	% Total	Solids t/	FractionNo	Fraction nan	neFraction m% N	ote -		Cu %	Fe %
ROM	?	SAG			225	0	Bulk				1.040122	6.786275
SAG Discharge	SAG	Cyclone				0	Bulk				0.989001	6.836096
Cyclone UF	Cyclone	SAG			250	0	Bulk				1.040242	7.127088
Cyclone OF	Cyclone	Rougher			225	0	Bulk				0.989115	7.379699
RC	Rougher	1st Cleaner				0	Bulk				12.4814	41.66124
CC1	1st Cleaner	2nd Cleaner				0	Bulk				10.9394	48.75182
Final Concentra	2nd Cleaner	?				0	Bulk	1000			15.75383	48.01802
RT	Rougher	Scavenger				0	Bulk				0.193961	4.137773
SC	Scavenger	1st Cleaner				0	Bulk				4.303134	43.78948
Final Tail	Scavenger	?				0	Bulk				0.051718	4.474968
CTO	2nd Cleaner	1st Cleaner				0	Bulk				3.009419	51.93595
CIZ							-				and the second se	

Fig. 21. Horizontal unsized data.

The program automatically detects a sheet named Streams as the sheet where the measurement data can be found. If the name of the sheet containing the measurement data is not Streams, the user should tell the program where the measurement data can be found (**Fig. 23**, Analyses)

The following screenshots show how an HSC7 file is imported. Importing an HSC7 file is started by clicking Tools-Mass Balancing and then clicking the Import HSC7 Data button (**Fig. 22**). After that a dialog will open (**Fig. 23**).

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HSC Sim 8 - Mass Balance			_	. • ×
Open Save Save As	Import HSC7 Data Import ReX Data	<b>R</b> Tools		
Balancing Navigator A X	Selected Unit Name	<ul> <li>PSD Changing</li> </ul>	Properties	ġ X
Experimental Data ^				
<u>Units</u> Streams Variables Size Fractions Data Sets Measurement Data				
🛃 Data Status 🔷				
Stream View Variable View				
A Standard Deviations				
SD - Stream View SD - Variable View				
Balancing				
Calculate Compare				
Reporting ^				
Results				

Fig. 22. Import HSC7 Data.

HSC/Data	
General	Analyses
Dimension	Select Analyses Sheets
ID - Unsized Data	Flowsheet
0 1.5D - Size Fraction Data	Streams
O 2D - Size Fraction With Assays	Units Units MineralMatrix *
Direction	
	Flowsheet
Vertical Data	Seet nowsheet
lonzontal bata	O [Nothing] O Units
	<ul> <li>Flowsheet</li> <li>MineralMatrix</li> </ul>
	O Streams O Balanced
	Flowsheet Direction
	Units Horizontal
	O Streams Horizontal

Fig. 23. Import HSC7 Data Dialog.

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### 51.5. Mass balance buttons and dropdowns



Update and save changes to HSC Sim flowsheet and close



Discard changes and close HSC mass balance



Open/Save backup (HSCMas file) of the mass balance



Import existing HSC7 mass balance data (analyses.xls)



Error check



Help and examples



Detects stream types automatically for Solid/slurry and Liquid based on the data. If there are streams with no data the stream type is set as Unknown. The user should either uncheck these Unknown streams or set the types manually



Select elements from periodic table



Select minerals from HSC database



Add new variable



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%<del>-∕∕</del> Sol-% to Water

Converts solids percentage measurements to water flow rates



Back calculate missing data if possible



Clear back calculated missing data



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View the mass balance equations



Unselect the streams without data



Exclude all elements (A) and do balancing with minerals (M)



Set component sum=100 when balancing minerals



Select calculation method. The available methods are LS, NNLS, and CLS



PSD balance: Possible selections are Unsized, Sized and Sized by Assays



Select the data to be balanced



Calculates mass balance



Clears the mass balancing results



Create or update HSC Sim stream tables

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### 51.6. Error check messages

- Dataset: No Active dataset found

   Please contact the developers
- Units: No selected units found
   At least one unit should be selected
- Streams: No selected streams found
  Some of the streams should be selected
- 4. Units: No input stream
  - Found a unit with no input streams
- 5. Units: No output stream
  - Found a unit with no output streams
- 6. Streams: Source and destination missing
  - Found a stream with no source and destination
- 7. Fractions: Bulk not found
  - Please contact the developers
- 8. Data: No data found
  - Add data in the measurement data view
- 9. Variables: Total solids measurement missing
  - There should be exactly one selected variable of the Total Solids type
- 10. Variables: Too many variables of the type total solids
  There should be exactly one selected variable of the Total Solids type
- 11. Variables: No selected assays found
  - There should be at least one selected variable of the Mineral Assay or Solids Component Assay type
- 12. Streams: All stream types unknown
  - Go to Streams and press Detect Stream Types button or set the stream types manually
- 13. User Values: UserValues missing
  - ValueStatus of some data is set to Fixed or Questimated but the UserValue is not given
- 14. Stream Types: Unknown found
  - Go to Streams and press Detect Stream Types button or set the stream types manually
- 15. Variables: Size Fraction wt % variable missing
  - There should be exactly one variable of the type Size Fraction wt %
- 16. Variables: Too many variables of the type Size Fraction wt-%
  - There should be exactly one variable of the type Size Fraction wt %
- 17. Units: No combined units found
  - There can be several reasons why combined units cannot be formed. There may be too many missing measurements or there may be errors in the flowsheet.
- 18. Notification: Min or Max values detected: It is recommended to use the CLS method

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#### 51.7. Mathematics and algorithms

In this section, the main algorithms and methods for data reconciliation in HSC Chemistry® 8 are briefly summarized.

### **Definitions**

$N_{F1}$	=	number of flows, unsized
N <sub>F2</sub>	=	number of flows, sized, sized by assay
$N_U$	=	number of units
N <sub>SRU</sub>	=	number of size-reducing units (PSD changing unit)
N <sub>SF</sub>	=	number of sub-flows
N <sub>E</sub>	=	number of chemical elements
G	=	grade of chemical element
$G^{\scriptscriptstyle M}$	=	measured grade of chemical element
F	=	solids flow rate
$F^{M}$	=	measured solids flow rate
W	=	water flow rate
$W^{\!\scriptscriptstyle M}$	=	measured water flow rate
Рс	=	$\text{\%solids} = F^{100}/(F + W)$
$Pc^{M}$	=	measured %solids
Μ	=	fraction m% = $F_{flow,subflow}$ *100/ $F_{flow}$
$M^{\!\scriptscriptstyle M}$	=	fraction m% measurements
	,	
	1	the flow enters the unit

$$e_{flow}^{unit} = \begin{cases} 1, the flow enters the unit \\ -1, the flow exits the unit \\ 0, otherwise \end{cases}$$

#### 51.7.1. Unsized (bulk) mass balance

In the unsized (bulk) mass balance solution, solids and water flow rates are solved first. After that the bulk analyses are solved. During the calculation: 1) the solids flow rates are solved first and after that 2) the water flow rates are solved.

#### 1. **Bulk flow rates**

The equations for solving the bulk solids flow rate are:

mass balance Equations (2)

$$\sum_{flow=1}^{N_{F1}} e_{flow}^{unit} * F_{flow,tot} = 0 \qquad unit = 1, ..., N_U$$
(2)

analyses Equation (3)



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$$\sum_{\text{flow}=1}^{N_{F1}} e_{\text{flow}}^{\text{unit}} * G_{\text{flow,tot,chemical\_element}}^{M} * F_{\text{flow,tot}} \approx 0 \quad \text{unit} = 1, \dots, N_{U}$$
(3)

chemical \_ element = 1,...,  $N_E$ 

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solids flow rate measurements (4)

$$F_{flow,tot} \approx F_{flow,tot}^{M} \qquad flow = 1, \dots, N_{F1}$$
(4)

The equations for solving the bulk water flow rate are:

mass balance Equations (5)

$$\sum_{flow=1}^{N_{F1}} e_{flow}^{unit} * W_{flow,tot} = 0 \qquad unit = 1, ..., N_U$$
(5)

water flow rate measurements Equation (6)

$$W_{flow,tot} \approx W_{flow,tot}^M$$
  $flow = 1,..,N_{F1}$  (6)

% solids measurements (7)

$$(Pc^{M}/100) * W_{flow,tot} \approx F_{flow,tot} - (Pc^{M}/100) * F_{flow,tot}$$
 flow = 1,.., N<sub>F1</sub> (7)

Mass balance Equations (2) and (5) are the equality constraints for the solutions. The solution method used is element-wise weighted total least squares<sup>2</sup>. The weights are standard deviations of the solids flow rate measurements  $F^{M}$ , the analyses  $G^{M}$ , the water flow rate measurements  $W^{M}_{,,}$  and the %solids measurements  $Pc^{M}$ . The flow rates can be solved without any constraints (LS), subject to non-negativity constraints (NNLS)<sup>3</sup>, and subject to simple bounds

 $lb1 \le F \le ub1$  $lb2 \le W \le ub2$ 

 $(CLS)^4$ .

#### 2. Bulk analyses

Let G and  $G_M$  be  $N_{F1} \times N_E$  matrices. The operator vec stacks the matrix columns into a vector.

The equations for the analyses solution are:

measurements (8)

$$vec(G) \approx vec(G^M)$$
 (8)

mass balance Equations (9) for the analyses:

$$\operatorname{vec}(B^*G) = 0 \tag{9}$$

where the  $N_U x N_{F1}$  matrix B is defined:

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$$B_{unit,flow} = e_{unit}^{flow} * F_{flow,tot}$$
(10)

If the option minerals sum=100 is selected, the following Equations (11) are included:

$$\sum_{\substack{l=1\\chemical element=1}}^{N_E} G_{flow,tot,chemical\_element} = 100 \qquad flow = 1,...,N_{F1}$$
(11)

Equations (9) and (11) are the equality constraints for the solution. The solution method used is weighted least squares 1). If Equations (11) are included in Equations (9), the matrix B is  $(N_U - 1) \times N_{F1}$  to avoid linear dependency of equality constraints.

As before, the analyses can be solved without any constraints (LS), subject to nonnegativity constraints (NNLS), and subject to simple bounds (CLS). If there are no constraints, the minimal maximum norm solution can be calculated (LS, MinMax)<sup>5</sup>.

### 51.7.2. Sized mass balance (without sized analyses)

Sized mass balance differs from unsized (bulk) solution in that the fraction m% is solved and the fraction m% measurement is used in the solution of total flows. Sized differs from Size by Assay in that the analyses are not given and the number of flows is the same as in the unsized case.

#### 1. Total flow mass balances of the streams

Firstly, the total flows are solved. The Equations are:

mass balance Equations (12)

$$\sum_{flow=1}^{N_{F1}} e_{flow}^{unit} * F_{flow,tot} = 0 \qquad unit = 1,..,N_U$$
(12)

fraction m% measurements (13)

$$\sum_{\text{flow}=1}^{N_{F1}} e_{\text{flow}}^{\text{unit}} * M_{\text{flow,subflow}}^{M} * F_{\text{flow,tot}} \approx 0 \qquad unit = 1, \dots, N_{U} - N_{SRU} - 1$$

$$subflow = 1, \dots, N_{SF}$$
(13)

Units are indexed up to  $N_U$  -  $N_{SRU}$  - 1 to avoid linear dependency of equality constraints.

Flow measurements (14)

$$F_{flow,tot} \approx F_{flow,tot}^{M} \qquad flow = 1, \dots, N_{F1}$$
(14)

If 1D analyses are given, the following Equations are included:

analyses (15)

$$\sum_{\text{flow}=1}^{N_{F1}} e_{\text{flow}}^{\text{unit}} * G_{\text{flow,tot,chemical\_element}}^{M} * F_{\text{flow,tot}} \approx 0 \quad \text{unit} = 1, \dots, N_{U}$$
(15)

chemical \_ element = 1,...,  $N_E$ 



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Equations (12) are equality constraints for the solution. The solution method used is element-wise weighted total least squares. The weights are standard deviations of the solids flow rate measurements  $F^M$ , the analyses  $G^M$  and fraction m%  $M^M$ .

As before, the flow rates can be solved without any constraints (LS), subject to nonnegativity constraints (NNLS), and subject to simple bounds (CLS). If there are no constraints, the minimal maximum norm solution can be calculated (LS, MinMax)<sup>5</sup>.

### 2. Size fraction flow mass balance

Then the %m values of the sub-flows are solved. The equations are:

fraction m% measurements (16)

$$M_{flow,subflow} \approx M_{flow,subflow}^{M} \tag{16}$$

mass balance equations (17)

$$\sum_{flow=1}^{N_{F1}} e_{flow}^{unit} * M_{flow,subflow} * F_{flow,tot} = 0 \qquad unit = 1,...,N_U \text{ unit not size reducing}$$

$$subflow = 1,...,N_{SF}$$
(17)

sum fraction m% is a hundred (18)

$$\sum_{i=1}^{N_{SF}} M_{flow,subflow} = 100$$
(18)

Equations (17) and (18) are equality constraints. The solution method used is element-wise total least squares and %m values can be solved without any constraints (LS), subject to non-negativity constraints (NNLS), and subject to simple bounds (CLS).

### 3. Bulk analyses

If the unsized bulk analyses are given, the balanced analyses are calculated as described above (see: unsized mass balance).

### 51.7.3. Sized by assay mass balance

Before a *sized by assay* mass balance solution, the *unsized* or *sized* mass balance must be solved first. The results  $F_{flow,tot}$  of the *unsized* or *sized* solution are used in the *sized by assay* solution. In a *sized by assay* solution, the size fraction sub-flows are calculated first and after that the analyses are solved.

### 1. Sized by assay fraction sub-flows

The equations for size by assay sub-flow solutions are:

mass balance Equations (19) for each unit that is not size reducing

$$\sum_{flow=1}^{N_{F2}} e_{flow}^{unit} * F_{flow,subflow} = 0 \quad unit = n_1, ..., n_{NU-1} \quad unit \text{ not size reducing}$$
(19)

subflow = 1,.., 
$$N_{\rm S}$$

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Above  $n_i$  is the index of the ith unit that is not size reducing. Units are indexed up to  $N_U$  - 1 to avoid linear dependency of equality constraints.

Sum of sub-flows is the total flow (20)

$$\sum_{subflow=1}^{NS} F_{flow,subflow} = F_{flow,tot} \qquad flow = 1,...,N_{F2}$$
(20)

Analyses for each unit that are not size reducing (21)

$$\sum_{\text{flow}=1}^{N_{F2}} e_{\text{flow}}^{\text{unit}} * G_{\text{flow,chemical_element,sublow}} * F_{\text{flow,subflow}} \approx 0$$

$$\text{unit} \quad \text{producting} \qquad (21)$$

$$unit = n_1, ..., n_{NU} \quad unit \quad not \quad size \quad reducing$$

$$chemical\_element = 1, ..., N_E$$

$$subflow = 1, ..., N_S$$

$$(21)$$

Fraction %m measurements (22)

$$F_{flow,subflow} \approx M_{flow,subflow}^{M} * F_{flow,tot} / 100$$
  
flow = 1,..., N<sub>F2</sub> (22)  
subflow = 1,..., N<sub>S</sub>

or alternatively

flow measurements (23)

$$F_{flow,subflow} \approx F_{flow,subflow}^{M}$$

$$flow = 1, ..., N_{F2}$$

$$subflow = 1, ..., N_{S}$$
(23)

The solution method used is element-wise weighted least squares. The equations can be solved without any constraints (LS), subject to non-negativity constraints (NNLS), and subject to simple bounds (CLS).

### 2. Sized by assay fraction analyses

Let *G* and  $G^M$  be  $N_{F2^*NS} \times N_E$  matrices. The operator *vec* stacks the matrix columns into a vector.

The equations for the analyses solution are:

$$vec(G) \approx vec(G^M)$$
 (24)

mass balance equations (25) for the analyses

$$vec(B^*G) = 0 \tag{25}$$

where the  $(N_{\text{S}}$  - 1)\*( $N_{\text{U}}$  -  $N_{\text{SRU}})x(N_{\text{F2}}\text{*}(N_{\text{S}}\text{-}1))$  matrix B is defined

$$B = diag(B^{subflow}) \qquad sublow = 1, .., N_{s} - 1$$
(26)



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> Sub-flows are indexed up to  $N_s$  - 1 to avoid linear dependency of equality constraints. Where the operator *diag* adds matrices  $B^{subflow}$  at the diagonal of the matrix B and

$$B_{unit,flow}^{sublow} = e_{flow}^{unit} * F_{flow,subflow}$$
(27)

the sum of sub-flows is the total flow (28)

$$\sum_{subflow=1}^{NS} F_{flow,subflow} * G_{flow,chemical\_element,subflow} = F_{flow,tot} * G_{flow,tot,chemical\_element}$$

$$flow = 1,...,N_{F2}$$

$$chemical\_element = 1,...,N_{F}$$
(28)

If the option minerals sum=100 is selected, the following Equations (29) are included:

$$\sum_{\substack{N_E \\ chemical element=1}}^{N_E} G_{flow, chemical\_element, subflow} = 100 \qquad flow = 1, \dots, N_{F1}$$
(29)

subflow = 1,..., $N_{\rm S}$ 

If Equations (29) are included, *B* is  $(N_s - 1)^*(N_U - N_{SRU} - 1)x(N_{F2}^*(N_s - 1))$  to avoid linear dependencies.

The solution method used is weighted least squares. The equations can be solved without any constraints (LS), subject to non-negativity constraints (NNLS), and subject to simple bounds (CLS).



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