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Balancing of raw washability data using spreadsheet optimization routine

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A technique for balancing raw washability data utilizing spreadsheet program is proposed and demonstrated by a working example. The sum of squares of the relative errors between raw and estimated data is minimized. The generated balanced data satisfy mass and ash balance conditions.

Keywords: Coal preparation, Mineral processing, Spreadsheet tools, Washability data balancing

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Introduction

Washability studies are conducted primarily to determine how much coal of what quality can be produced at a given specific gravity with what separation complexity[1]. Washability study of coal is made by float-and-sink analysis and testing of coal sample at pre-selected and carefully controlled specific gravities. Specific gravity fractions are dried, weighed, and analyzed for ash content or for other assay depending upon end use of washed coal. Data are mathematically combined on a weighted basis into cumulative float and sink for developing washability curves to characterize coal. These tests are subjected to experimental errors due to improper sampling procedures and unreliable laboratory analyses. So it is desirable to minimize such errors for reliable results in density separation performance prediction and estimation[2-3].

A spreadsheet-based mass balance program has been developed using optimization tools embedded in modern spreadsheet programs, to reconcile conflicting raw washability data.

Problem Formulation

In float-and-sink analysis, fractions floating and sinking at a particular relative density represent cumulative masses. Corresponding cumulative ash contents are determined by conducting an ash analysis on each float and sink fractions (Table 1). Relative error squares between the estimated and raw data is given by

$$\Phi = \sum_{i=1}^{N-1}\left[\left(\frac{M^{o}{}_{fi}}{\hat{M}^{o}{}_{fi}}-1\right)^2+\left(\frac{M^{n}{}_{fi}}{\hat{M}^{n}{}_{fi}}-1\right)^2+\left(\frac{M^{o}{}_{s(i+1)}}{\hat{M}^{o}{}_{s(i+1)}}-1\right)^2+\left(\frac{M^{n}{}_{s(i+1)}}{\hat{M}^{n}{}_{s(i+1)}}-1\right)^2\right]$$
$$+\left[\left(\frac{1-A}{\hat{M}^{o}{}_{fN}}-1\right)^2+\left(\frac{A}{\hat{M}^{n}{}_{fN}}-1\right)^2+\left(\frac{1-A}{\hat{M}^{o}{}_{st}}-1\right)^2+\left(\frac{A}{\hat{M}^{n}{}_{st}}-1\right)^2\right] \quad ...(1)$$

subjected to constraints

$$M^{o}{}_{fi}+M^{o}{}_{s(i+1)}=1-A \quad ...(2)$$

$$M^{n}{}_{fi}+M^{n}{}_{s(i+1)}=A \quad ...(3)$$

Minimization problem presented is a classical constrained optimization problem and can be solved analytically by utilizing the constant multipliers method[5].

Proposed Technique

Proposed method is to make use of spreadsheets, in which optimization routines like SOLVER for Microsoft excel. For minimization of Φ, SOLVER can be used to minimize a target cell calculated by using Eq. (1) by adjusting cumulative mass and cumulative ash for float and sink values subject to constraints calculated from Eqs (2) and (3). SOLVER allows user to have direct control over many of the criteria used in the adjustment of data (degree of precision, error tolerance, degree of convergence, iteration method, etc). Ability to perform

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Table 1— Cumulative raw and balanced washability data

	Measured value				Adjusted value			
Relative density	Float		Sink		Float		Sink	
fraction	Mass, %	Ash, %	Mass, %	Ash, %	Mass, %	Ash, %	Mass, %	Ash, %
Float-1.3	6.22	1.13	100	20.18	6.2184	1.1303	100	19.4311
1.3 -1.35	15.45	2.78	93.78	20.39	15.4706	2.775	93.7816	20.6445
1.35 -1.4	31.8	3.58	84.55	22.96	31.8965	3.5651	84.5294	22.4795
1.4 -1.45	44.93	6.7	68.2	27.34	45.1519	6.6376	68.1035	26.862
1.45 -1.5	60.04	9.24	55.07	30.6	60.2636	9.1341	54.8481	29.9629
1.5 -1.6	76.59	11.39	39.96	35.56	77.238	10.8112	39.7364	35.0474
1.6 -1.7	82.78	12.46	23.41	50.23	83.455	11.5607	22.762	48.6808
1.7 -1.8	88.62	12.49	17.22	60.8	88.5389	12.6721	16.545	59.1303
1.8 -2.0	94.03	13.82	11.38	71.44	93.8282	15.5231	11.4611	71.6456
2.0 -2.2	95.51	14.76	5.97	78.12	95.4061	16.2819	6.1718	78.8428
2.2 -Sink	100	20.18	4.49	84.48	100	19.4311	4.5939	84.8335

high-level minimization without extensive programming makes this approach very powerful. The limitations imposed by Eqs (2) and (3) must also be entered as constraints within SOLVER dialog box.

Results

Balanced washability data are adjusted values (Table 1) using spreadsheet-based approach, which matches quite well with the least-squares approach[5].

Conclusions

Establishment of a consistent mass balance in balancing raw washability data is a key step in the analysis of washability characteristics of a coal sample. Unfortunately, this task can be difficult when redundant or conflicting data are obtained experimentally. To help resolve this problem, a spreadsheet-based approach for reconciling mass balance data has been presented. This technique makes use of minimization tools that are now available in most modern spreadsheet programs and is useful for plant engineers to perform day-to-day study of washability characteristics of different coal.

Nomenclature

ρ_i = Density

$\hat{M}_{fi}$ = Total float mass

$\hat{A}_{fi}$ = Float ash mass

$\hat{M}_s$ = Total sink mass

$\hat{A}_s$ = Sink ash mass

$\hat{M}^o_{fi}$ = Float mass of organic components

$\hat{M}^o_s$ = Sink mass of organic components

$\hat{M}^n_{fi}$ = Float mass of non organic components

$\hat{M}^n_s$ = Sink mass of non organic components

A = Modified overall ash content of the sample

$M^o_{s(i+1)}$ = Estimated sink mass of organic components in density range $\rho_{i-1} - \rho_i$

$M^n_{s(i+1)}$ = Estimated sink mass of non organic components in density range $\rho_{i-1} - \rho_i$

M^n_{fi} = Estimated float mass of non organic components in density range $\rho_{i-1} - \rho_i$

M^o_{fi} = Estimated float mass of organic components in density range $\rho_{i-1} - \rho_i$

$\hat{M}^o_{fN}$ = Float mass of organic components in N^{th} density range

$\hat{M}^n_{fN}$ = Float mass of non organic components in N^{th} density range

$\hat{M}^o_{st}$ = Sink mass of organic components in 1^{st} density range

$\hat{M}^n_{st}$ = Sink mass of non organic components in 1^{st} density range

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