ОБОГАЩЕНИЕ ПОЛЕЗНЫХ ИСКОПАЕМЫХ

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Analysis and optimization of sample preparation schemes

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Abstract

Introduction. *Sample preparation is an integral part of the sampling technology. The process flow scheme for sample preparation can consist of five or more stages associated with the sample material size change and mass reduction.*

Objective and preparation. *In the course of preparation, the random sampling error increases depending on the fineness and final sample mass selected at each stage during sample reduction. A working calculation formula for the relative random error of the sample preparation scheme is proposed. The formula includes a scheme coefficient calculated using values constant for the sample: the density of the mineral containing a valuable component, the component mass fraction in the mineral, the mineral grain size, and the valuable component mass fraction in the sample. According to the developed preparation scheme, the summands are written down, which are determined by the sample material size and the final mass of the reduced sample. The summands calculated for each stage make it possible to determine the contribution of each stage to the relative random error and change the scheme's parameters, taking into account the processing capabilities of the crushing and grinding equipment. Theoretically, all sample preparation scheme stages should make almost the same contribution to random error.*

Conclusions. *Practical calculations of preparation schemes for 80 and 10 mm tin ore samples have shown that the schemes developed in accordance with GOST 14180-80 are not optimal. Changing sample size and weight by scheme stages made it possible to reduce random errors in half.*

Results. *The sample preparation scheme was optimized to minimize random error. By introducing other objective functions and restrictions, it is possible to optimize the scheme to obtain maximum equipment performance or minimum energy consumption.*

Keywords: *sample preparation; preparation stages; sample reduction; relative random error; scheme optimization.*

Introduction. Lump sampling at preparation plants results in large initial samples. Thus, when sampling ore mined by the underground method at copper-zinc mills, the initial sample weight is 480 kg, and at tin mills – 1280 kg, which is associated with the following requirements: sampler bucket width must be greater than three sizes of the biggest (d_{95}) ore lumps and a certain required number of point samples must be collected.

The use of automatic on-stream analyzers is followed by problems in calibration and readings monitoring, which also requires collecting large samples.

Initial samples from lumps require preparation to a size and weight suited for analysis. Sample preparation schemes are multi-stage because of a large sample size compared to the size required for analysis. In these schemes, the sample size and mass to which samples are reduced at each stage are assigned approximately, based on the processing capabilities of the crushing and grinding laboratory equipment. Sample preparation is important not only for prompt and commercial sampling of lump ore [1], but also when using high-performance mass fraction analyzers at enterprises [2], both for non-ferrous metal ore [3], and at iron processing plants [4] and gold beneficiation plant [5]. Sample preparation is necessary for all sampling forms during the research process [6], both directly at processing plants [7] and in laboratories [8].

Sample preparation also includes a process step that is usually performed by analysts, namely, collecting a subsample: the subsample used directly for analysis [9] for any type of analysis [10], regardless of the type of equipment used [11], including spectral analyzes [12].

Research objective is to present alternatives for preparation schemes calculation and logical optimization.

Theory. The general methods for calculating relative random sampling errors is described in [13].

The relative random error of the sample preparation scheme P_{prep} is calculated depending on the established final fineness d_j at each j-th stage and the final mass of the sample reduced at the j-th stage q_j:

$$P_{\text{prep}}^2 = K_{\text{sch}} \left(\sum_{j=1}^{l} \frac{d_j^b}{q_j} + \sum_{j=l+1}^{k} \frac{d_j^3}{q_j d_{\text{grain}}^{3-b}} \right), \tag{1}$$

where d_j is the sample material size at the j-th stage, mm; b is the impregnation nature indicator, for ore b = 1.5; q_j is the mass of the sample reduced at the j-th stage, kg; d_{grain} is the grain size of the mineral containing the component being determined, mm; 1…l are the stages where $d \geq d_{\text{grain}}$; l+1…k are the stages where $d < d_{\text{grain}}$; K_{sch} is the scheme coefficient, calculated using additional data on the sample by formula

$$K_{\text{sch}} = \frac{K_{\text{prep}} \cdot f \cdot \rho_{\text{m}} \cdot \beta_{\text{m}} \cdot d_{\text{grain}}^{3-b} \cdot 10^{-5}}{\alpha},$$

where K_{prep} is a coefficient that takes into account the quality of performance, K_{prep} = 2 [14]; f is the grain shape coefficient, f = 0.4; ρ_{m} is the density of the mineral containing the component being determined, kg/m^3; β_{m} and α are the mass fraction of the determined component in the mineral and in the ore, respectively, %, g/t.

For the calculated sample preparation scheme, K_{sch} is a constant with a dimension that gives a relative random error in percentage terms when calculated using formula (1).

The summands in brackets in formula (1) provide information about the contribution of each stage of the sample preparation scheme to the final error. By changing the mass of samples being reduced and the size at certain stages, it is possible to optimize the preparation scheme.

The scheme optimization is aimed at minimizing the relative random error with restrictions on the grinding equipment reduction ratio and performance [15].

Practical calculations. To prepare an initial sample weighing 1280 kg when collecting samples from the 80 mm material, a five-stage sample preparation scheme was drawn up, Figure 1, *a*, corresponding to the standard GOST 14180-80 diagram.

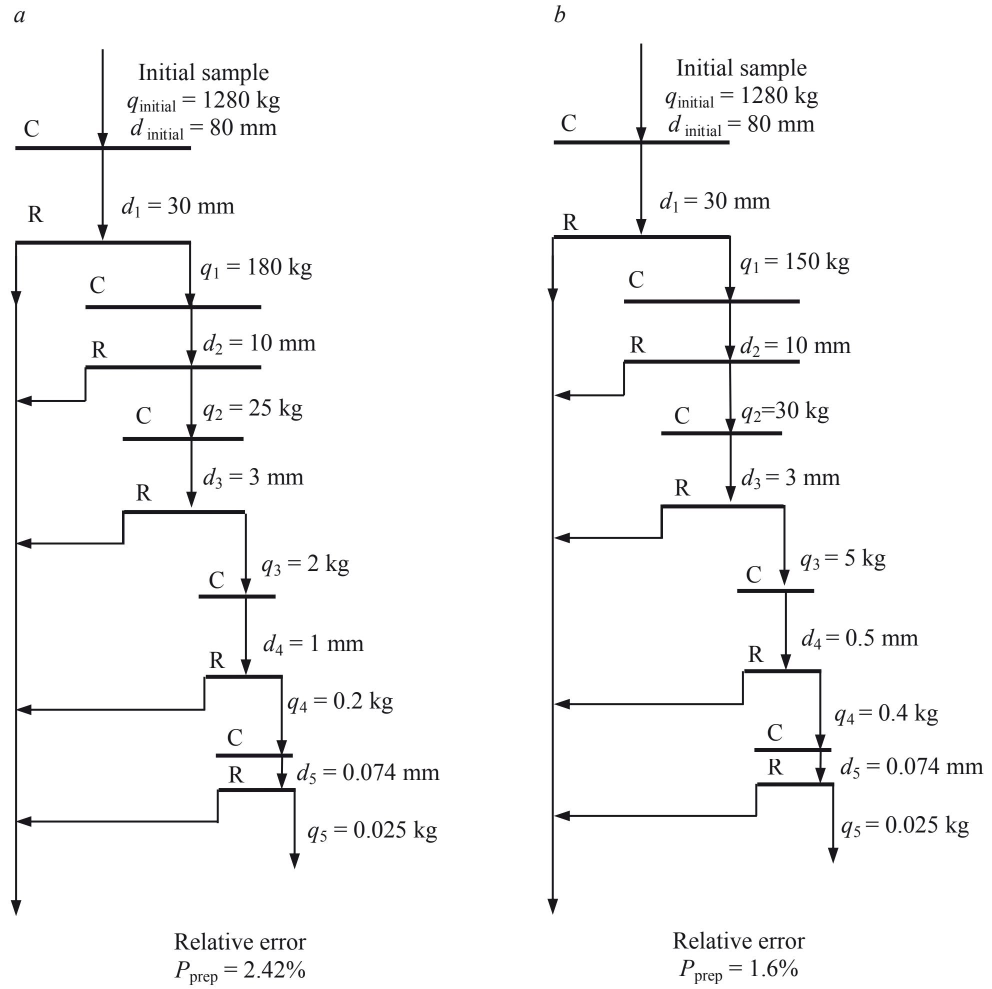

Figure 1. Designed – *a* and optimized – *b* schemes of 80 mm sample preparation (C – crushing, R – reduction)

Рисунок 1. Запроектированная – *a* и оптимизированная – *b* схемы подготовки пробы крупностью 80 мм (C – операция дробления, R – сокращение пробы)

To determine K_{sch} of the scheme, the following was established: mineral cassiterite, density $\rho_m = 7000$ kg/m^3, mass fraction of tin in cassiterite is 78.8%, mass fraction of tin in ore is 0.67%, cassiterite grain size is $d_{grain} = 0.2$ mm.

Then

$$K_{sch} = \frac{2 \cdot 0{,}4 \cdot 7000 \cdot 78{,}8 \cdot 0{,}2^{3-1{,}5} \cdot 10^{-5}}{0{,}67} = 0{,}59$$

and relative random error according to formula (1)

$$P_{prep}^2 = 0{,}59\left(\frac{30^{1{,}5}}{180} + \frac{10^{1{,}5}}{25} + \frac{3^{1{,}5}}{2} + \frac{1^{1{,}5}}{0{,}2} + \frac{0{,}074^3}{0{,}025 \cdot 0{,}2^{3-1{,}5}}\right) =$$
$$= 0{,}59\left(0{,}913 + 1{,}265 + 2{,}598 + 5{,}0 + 0{,}160\right) = 5{,}862\%^2.$$

Consequently, the relative random error of the pre-designed sample preparation scheme P_{prep} = 2.42%. Formula (1) makes it possible to determine the scheme's weaknesses (the summands in brackets). First of all, the poorly planned fourth stage which gives a summand equal to 5.0, as well as the third stage which gives a summand equal to 2.598.

Let us propose the following changes to the scheme: in the first stage let us reduce the sample to 150 kg, in the second stage, reduce the sample to 30 kg, in the third stage, reduce the sample to 4 kg, in the fourth stage, crush the sample to 0.5 mm and reduce it to 0.4 kg. Let us leave the remaining values in the scheme unchanged.

Then

$$P_{prep}^2 = 0{,}59\left(\frac{30^{1,5}}{150} + \frac{10^{1,5}}{30} + \frac{3^{1,5}}{5} + \frac{0{,}5^{1,5}}{0{,}4} + \frac{0{,}074^3}{0{,}025 \cdot 0{,}2^{3-1,5}}\right) =$$
$$= 0{,}59\left(1{,}095 + 1{,}054 + 0{,}987 + 0{,}884 + 0{,}181\right) = 2{,}479\%^2$$

and

$$P_{prep} = 1{,}6\%.$$

This means that a new sample preparation scheme has been obtained with a relative random error almost two times less than the designed one (Figure 1, *b*).

Another sample preparation scheme was designed for ore with a particle size of 10 mm, Figure 2, *a*. The scheme contains 3 stages. The ore is the same, so K_{sch} = 0.59, the initial sample weight is 20 kg.

Let us find the relative random error of the designed scheme:

$$P_{prep}^2 = 0{,}59\left(\frac{3^{1,5}}{2} + \frac{1^{1,5}}{0{,}2} + \frac{0{,}074^3}{0{,}025 \cdot 0{,}2^{3-1,5}}\right) =$$
$$= 0{,}59\left(2{,}598 + 5{,}0 + 0{,}181\right) = 4{,}59\%^2;$$
$$P_{prep} = 2{,}14\%.$$

Judging by the large difference between the summands in brackets, it is obvious that the scheme is not optimal.

Let us reduce the sample to 5 kg at the first stage, crush it to 0.5 mm and reduce it to 0.4 kg at the second stage. Then

$$P_{prep}^2 = 0{,}59\left(\frac{3^{1,5}}{5} + \frac{0{,}5^{1,5}}{0{,}4} + \frac{0{,}074^3}{0{,}025 \cdot 0{,}2^{3-1,5}}\right) =$$
$$= 0{,}59\left(1{,}039 + 0{,}884 + 0{,}181\right) = 1{,}241\%^2.$$
$$P_{prep} = 1{,}11\%.$$

As a result, a scheme was obtained that makes it possible to prepare a sample for analysis with an error two times less than that of the designed one (Figure 2, *b*).

Discussion. Sample preparation schemes are drawn up individually at each preparation plant; specialists are guided by the recommended GOST 14180-80 scheme and analyze the capability of crushing and reducing samples using existing equipment. This approach does not result in the best preparation schemes.

To obtain schemes that are close to optimal, it is necessary to calculate the relative random error of the pre-designed scheme using the formulae presented in this research. After that, using the calculation results by stages of preparation, change preparation scheme parameters so that all stages of preparation make an equal contribution to the random error. Changes should be made within the limits of the sample crushing and reduction ratios available for the existing equipment.

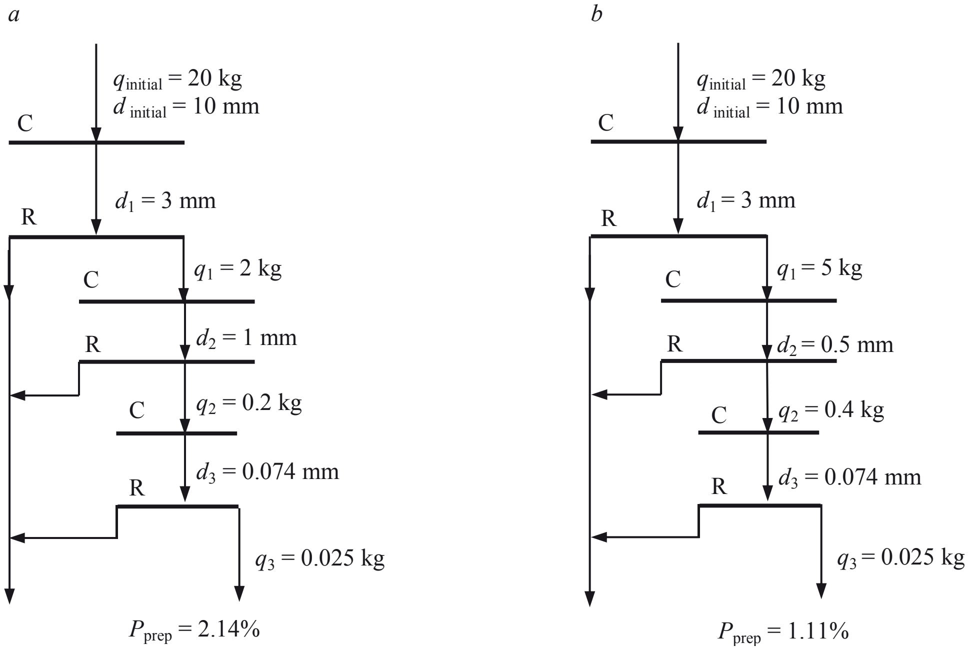

Figure 2. Designed – *a* and optimized – *b* schemes of 10 mm sample preparation (C – crushing, R – reduction)

Рисунок 2. Запроектированная – *a* и оптимизированная – *b* схемы подготовки пробы крупностью 10 мм (С – операция дробления, R – сокращение пробы)

If all the summands in formula (1) are the same, then the scheme will be optimal, i.e. leading to the smallest relative random error.

GOST 14180-80 recommendations for calculating reduced sample masses using the Richards–Chechott formula excludes this possibility [16], and factories use sample preparation schemes developed without calculations [17].

When analyzing samples, subsample collection is an additional operation of the sample preparation scheme. However, the introduction of the subsample collection scheme in the calculation will allow to discover additional reserves for reducing the random sampling error as a whole.

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Расчет и оптимизация схем подготовки проб

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Реферат

Введение. *Подготовка проб является необходимой процедурой в технологии опробования. Технологическая схема подготовки проб может состоять из пяти и более стадий, связанных как с изменением крупности материала пробы, так и с уменьшением массы.*

Цель и подготовка. *При подготовке проб случайная погрешность опробования увеличивается. Это увеличение зависит от выбранных на каждой стадии крупности дробления и конечной массы пробы при ее сокращении. Предложена рабочая формула* *расчета относительной случайной погрешности схемы подготовки проб. В формулу входит коэффициент схемы, рассчитываемый по постоянным для пробы величинам: плотности минерала, содержащего ценный компонент, и массовой доли этого компонента в минерале, крупности зерен минерала и массовой доли ценного компонента в пробе. Соответственно разработанной схеме подготовки записываются слагаемые, определяемые крупностью материала пробы и конечной массой сокращенной пробы. Полученные при расчете слагаемые по стадиям дают возможность определить вклад каждой стадии в относительную случайную погрешность и с учетом технологических возможностей дробильно-измельчительного оборудования изменить параметры схемы. Теоретически все стадии схемы подготовки пробы должны вносить примерно одинаковый вклад в случайную погрешность.*

Выводы. *Практические расчеты схем подготовки проб оловянной руды крупностью 80 и 10 мм показали, что разработанные в соответствии с ГОСТ 14180-80 схемы не оптимальны. Изменение крупности и массы пробы по стадиям схемы привели к снижению случайных погрешностей в два раза.*

Результаты. *Оптимизация схемы подготовки пробы выполнена с целью минимизации случайной погрешности. При введении других целевых функций и ограничений возможна оптимизация схемы с целью получения максимальной производительности оборудования или минимального расхода энергии.*

Ключевые слова: *подготовка пробы; стадии подготовки; сокращение пробы; относительная случайная погрешность; оптимизация схемы.*

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