

БОГАЩЕНИЕ ПОЛЕЗНЫХ ИСКОПАЕМЫХ

DOI: 10.21440/0536-1028-2022-5-77-87

Asymmetric distributions of desired component mass fraction in point samples

Vladimir Z. Kozin¹, Aleksei S. Komlev^{1*}

¹ Ural State Mining University, Ekaterinburg, Russia

*e-mail: tails2002@inbox.ru

Abstract

Introduction. Desired component mass fraction distributions in point samples at preparation plants are asymmetric, and it is due to the natural heterogeneity of ores.

The theory of mass fractions distribution asymmetry in samples. The theory is based on the lump sampling of point samples. Mass fraction distributions here consist of two different-sized fractions: valuable mineral and rock. These distributions are always asymmetric. Lump dispersion for asymmetric distributions depends on the mass fraction of the valuable mineral for both released grains and aggregates. Mass fraction distribution in point samples with poor product mass fraction is described by the Poisson formula.

Materials and methods of research. Mass fraction distribution correspondence to the Poisson formula was experimentally confirmed based on an artificial rock mass represented by quartz grit with colored markers. Point samples of different mass were collected from the rock mass.

Experimental estimates. The distributions obtained experimentally correspond to the distributions calculated by the Poisson formula. The paper introduces a method for experimental determination of valuable mineral average grain size and ore texture index. These values were determined for asbestos ore to exemplify the method proposed.

Results discussion. Sampling standards do not consider the asymmetry of mass fraction distributions in point samples. At preparation plants the asymmetry manifests itself in hurricane samples, positive product imbalance, and divergence of double weights analysis results, that exceed the acceptable limits. The asymmetry of components mass fraction distributions in concentrates should be taken into account in sampling standards and methods, as well as at preparation plants in general.

Keywords: point samples; mass fraction distributions; distribution asymmetry; lump sampling; average grain size; ore texture index.

Introduction. Mass fraction distribution in point samples is the only overall component mass fraction characteristic of the tested rock masses.

In practice, histograms are made, when required, and distribution normality or possible deviations are substantiated.

Foreign research papers often discuss the improvement of sampling systems [1–4], including hand sampling [5], as well as the development of mineralogical studies [6], calculation of standard sample error [7], and the development of the assaying method [8]. The indicated papers are based on normal distributions either directly or indirectly.

In the geological industry, when studying individual low-weight samples, it was noticed that normal mass fraction distributions in point samples of concentrates are still the exception rather than the norm [6]. At preparation plants, relatively high-weight samples are collected from partially mixed rock masses under test, which decreases the asymmetry of mass fraction distributions [7]. However, under lower mass fractions of desired components and higher quality of concentrates, the asymmetry of mass fraction distributions in point samples is more noticeable. This is also true for ore processing at preparation plants [8].

Figure 1 shows histograms of probable mass fraction distributions P for copper in ore (a) and tailings (b) at a copper-zinc preparation plant with a particularly pronounced right asymmetry. Figure 1 also shows histograms of copper mass fraction in copper concentrate (c) with left asymmetry and the copper (impurity component) mass fraction in zinc concentrate (d) with right asymmetry. Similar histograms are built at all preparation plants with a common pattern: right asymmetric distributions (histograms) are typical for products with poor mass fraction, while left asymmetric distributions are typical for products with rich mass fraction.

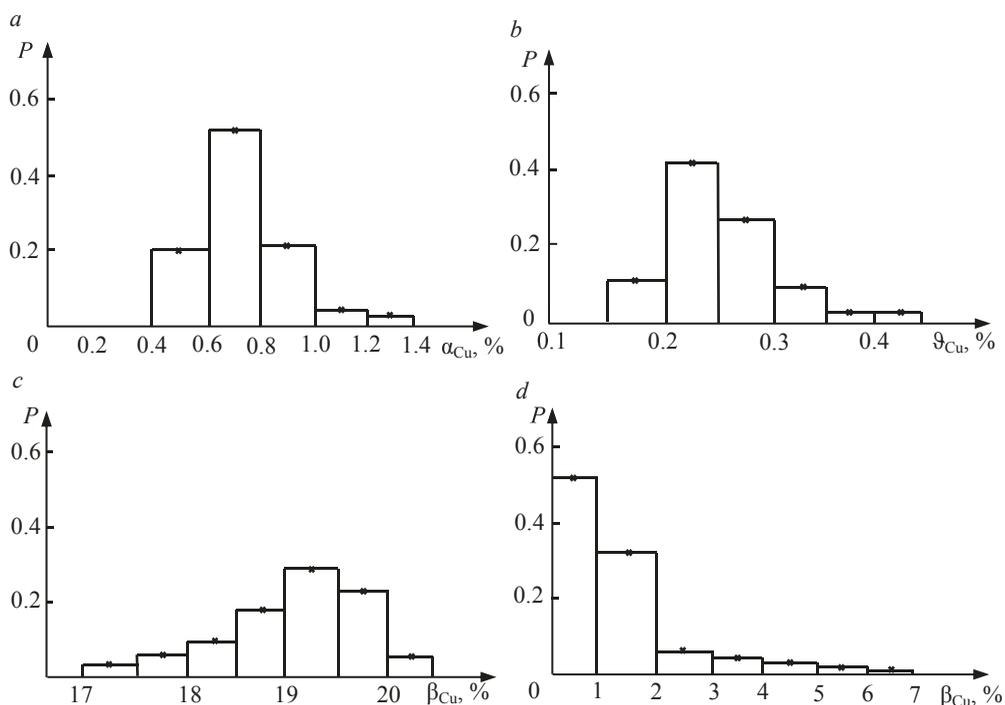


Figure 1. Histograms of copper mass fraction distribution in ore, tailings, copper and zinc concentrates: a – for copper in ore; b – for copper in tailings; c – for copper in copper concentrate; d – for copper in zinc concentrate

Рисунок 1. Гистограммы распределения массовой доли меди в руде, хвостах, медном и цинковом концентратах:

a – для меди в руде; b – для меди в хвостах; c – для меди в медном концентрате; d – для меди в цинковом концентрате

The natural heterogeneity of ores is considered to be the reason for the distributions asymmetry [9]. However, the terms and boundaries for ore heterogeneity have not been strictly defined. Without it, the crucial characteristic of mass fraction distribution in point samples can only be obtained experimentally.

The research objective is to substantiate reasons and quantify distributions based on the fundamental concept of lump collection of point samples (lump sampling). Lump sampling is the ultimate sampling variant in terms of its analytical description that helps to calculate possible distributions and explains their features.

The theory of mass fraction distributions asymmetry in samples. General fundamental conclusions about mass fraction distributions in point samples are obtained after the fundamental principles for the distributions formation have been determined. Solid minerals at preparation plants are represented by products broken in lumps.

The minimum amount of lumps of sampled material in a point sample n_{point} is one. The mass fraction distributions under $n_{point} = 1$ are limiting and can be considered fundamental. In this case, lump sampling is defined as sampling where one lump is collected into a point sample.

All the lumps in the tested rock mass are assumed to be uniform in size and fully released. A fully released lump is either pure mineral or rock. The analysis of such samples may provide only two numbers: $\beta_{mineral}$ is the mass fraction of the desired component in the pure mineral and 0 (zero), which is the mass fraction of the desired component in barren rock. As a result, a histogram consisting of two bars will be obtained during lump sampling (Figure 2). On the histograms, the right bars correspond to mineral grains fraction, and the left bars correspond to rock grains share. P_i on the y-axis denotes the probability of mineral and rock lumps occurrence. The histograms in Figure 2 are asymmetric. Histogram bars are generally of different heights. For ore and tailings, the right columns are usually much smaller than the left ones, and vice versa for concentrates. Therefore, ore and tailings distributions are considered to be right asymmetric, and for concentrates are left asymmetric.

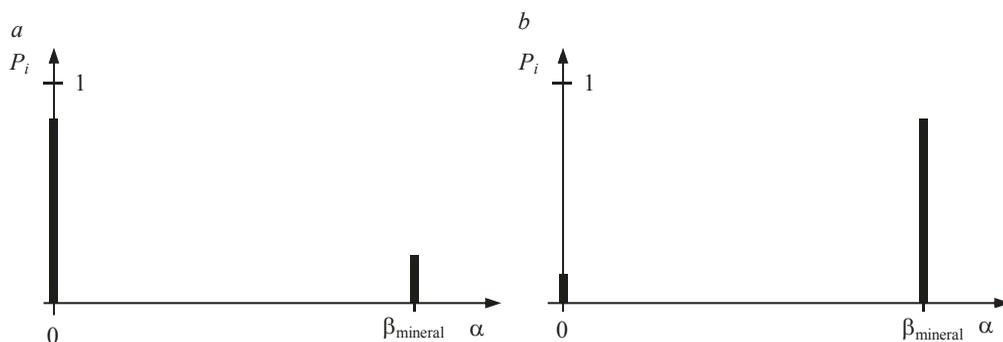


Figure 2. Histograms of valuable component mass fraction under lump sampling:

a – for a low-grade product; *b* – for a high-grade product

Рисунок 2. Гистограммы массовой доли ценного компонента при покусковом опробовании:

a – для бедного продукта; *b* – для богатого продукта

The mass fraction of a valuable (desired) component is thought of as the ratio between the mass of the desired component or mineral in the product and the mass of this product. The histograms (distributions) in Figure 2 are of fundamental importance for sampling because they are universal for any ore, tailings or concentrate.

So, lump dispersion S_{lump}^2 , determined by the following formula, is also a fundamental characteristic found based on the distribution data:

$$S_{lump}^2 = \frac{\rho_{mineral}}{\rho_{rock}} \alpha (\beta_{mineral} - \alpha) \left(1 - \frac{\alpha}{\beta_{mineral}} + \frac{\alpha \rho_{rock}}{\beta_{mineral} \rho_{mineral}} \right)^2.$$

Lump dispersion depends on four quantities, namely mineral and rock densities ($\rho_{mineral}$ and ρ_{rock} , respectively) and the component mass fraction in the valuable mineral in terms of stoichiometric ratio and ore ($\beta_{mineral}$ and α , respectively).

The dependence between the lump dispersion S_{lump}^2 and the mass fraction α is shown in Figure 3. Within the range $\alpha < 0,1\beta_{mineral}$ (the majority of ores and tailings), the lump dispersion formula is simple:

$$S_{\text{lump}}^2 = \frac{\rho_{\text{mineral}}}{\rho_{\text{rock}}} \alpha (\beta_{\text{mineral}} - \alpha) \quad \text{or} \quad S_{\text{lump}}^2 = \frac{\rho_{\text{mineral}}}{\rho_{\text{rock}}} \alpha \beta_{\text{mineral}}.$$

If the tested rock mass is represented by aggregates, the lump dispersion is determined by the following formula:

$$S_{\text{lump aggregates}}^2 = S_{\text{lump}}^2 \left(\frac{d_{\text{grain}}}{d} \right)^{3-b} \quad \text{under} \quad d > d_{\text{grain}},$$

where d is the lump size, d_{grain} is the size of valuable mineral grains, and number b denotes the nature of valuable component dissemination.

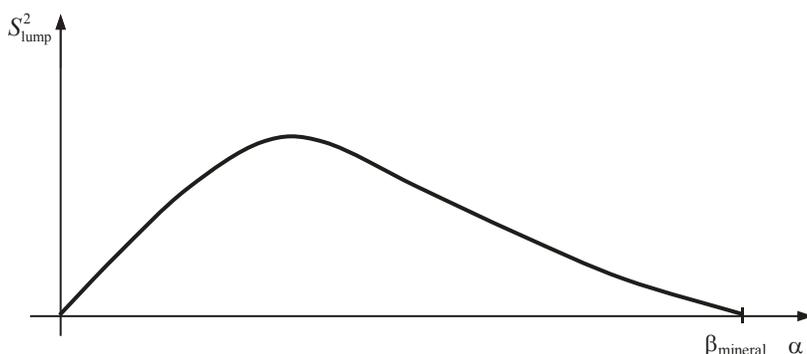


Figure 3. Dependence of the lump dispersion on the valuable component mass fraction α
 Рисунок 3. Зависимость покусковой дисперсии от массовой доли ценного компонента α

The latter depends on the lump structure (ore texture):

- for rare uniform dissemination $b = 0$;
- for vein-type dissemination $b = 1$;
- for laminated dissemination $b = 2$;
- for massive ore $b = 3$.

Lump size d and valuable component grain size d_{grain} are understood as square screen aperture size the material of the specified size passes through. Massive ore (released ore) is a limiting case, where $b = 3$, but $d_{\text{grain}} = d$ equality is satisfied. The concept of non-uniform dissemination with provisionally accepted $b = 1.5$ should be introduced.

Ore with $d < d_{\text{grain}}$ lump size is considered by convention to be released, while ore with $d > d_{\text{grain}}$ lump size is represented by aggregates.

If more than one lump is collected in a point sample, the number of histogram bars will change. If two lumps are collected in a point sample, three situations are possible: either both lumps are pure minerals or both lumps are waste or one lump is mineral while the other one is waste. So, the histogram will consist of three bars.

There will be a lot of bars on the histogram if sampling is carried out routinely at the preparation plant. The mass fraction of a valuable component for each bar can be found by the formula:

$$\alpha_{m, n \text{ point}} = \frac{m}{n_{\text{point}}} \cdot \frac{\rho_{\text{mineral}}}{\rho} \beta_{\text{mineral}},$$

where n_{point} is the number of lumps (of rock and aggregates of rock and mineral) collected in a point sample; m is the number of mineral grains that fell into the point sample;

ρ_{mineral} is the density of the mineral; ρ is the density of a sample; β_{mineral} is the mass fraction of the desired component in the mineral.

The following relationship is maintained:

$$\rho = \frac{m}{n_{\text{point}}} \rho_{\text{mineral}} + \left(1 - \frac{m}{n_{\text{point}}}\right) \rho_{\text{rock}},$$

where ρ_{rock} is rock density.

The histogram bar height is determined by the formula:

$$P_{m,n \text{ point}} = \frac{n_{\text{point}}!}{m!(n_{\text{point}} - m)!} P_{\text{mineral}}^m (1 - P_{\text{mineral}})^{n_{\text{point}} - m},$$

where $P_{m,n \text{ point}}$ is the fraction of samples consisting of n_{point} lumps, m lumps of pure mineral fell into; P_{mineral} is the numerical fraction of mineral grains in the tested rock mass.

P_{mineral} is determined by the formula:

$$P_{\text{mineral}} = \frac{\bar{m}}{n_{\text{point}}},$$

where \bar{m} is the average number of mineral lumps in a sample.

Mass fraction distribution in point samples, consisting of n_{point} lumps, remains asymmetric. It is possible to calculate this distribution, but we do not carry out practical calculation by the formula for $P_{m,n \text{ point}}$ due to a large number of bars.

Practical calculations and fundamental conclusions can be drawn for an important special case, when n_{point} is large, i.e. a lot of lumps are collected in a point sample, while \bar{m} is small. In this case, few mineral pieces fall in the point sample. The $n_{\text{point}} \gg \bar{m}$ inequality is therefore satisfied.

Expression for $P_{m,n \text{ point}}$ is transformed:

$$P_{m,n \text{ point}} = \frac{n_{\text{point}}(n_{\text{point}} - 1)(n_{\text{point}} - 2) \dots (n_{\text{point}} - m)!}{m!(n_{\text{point}} - m)!} \cdot \left(\frac{\bar{m}}{n_{\text{point}}}\right)^m \cdot \left(1 - \frac{\bar{m}}{n_{\text{point}}}\right)^{n_{\text{point}} - m}.$$

Since $n_{\text{point}} \gg \bar{m}$, this formula takes the following form

$$P_{m,n \text{ point}} = \frac{n_{\text{point}}^m}{m!} \cdot \frac{\bar{m}^m}{n_{\text{point}}^m} \left(1 - \frac{\bar{m}}{n_{\text{point}}}\right)^{n_{\text{point}}} = \frac{\bar{m}^m}{m!} e^{-\bar{m}}.$$

The distribution depends only on m and can be denoted by P_{mineral} :

$$P_{\text{mineral}} = \frac{\bar{m}^m}{m!} e^{-\bar{m}}.$$

This is the Poisson distribution formula.

The number of mineral lumps m can take on any integer values from zero and above (0, 1, 2, 3, etc.). The estimated mass fraction distributions for conditions $\bar{m} = 1$ and $\bar{m} = 3$ are shown in Figure 4. The average value of \bar{m} can be fractional.

Mass fraction distributions for small \bar{m} are extremely asymmetric.

Materials and methods of research. Valuable component mass fractions in point samples from a well-mixed mass are assumed to be different, and their distributions are assumed to be asymmetric. To experimentally verify this assumption, an artificial mass of quartz grains with a size of $-3+1.4$ mm was taken, and colored markers of the same size were placed to it. In the course of the experiment, 50 point samples were collected by the quartering method and with a riffle sample divider. On average, the 50 point samples could contain a small number of markers. For each point sample, the number of markers was calculated and the experimental distributions E were found. For each distribution, the average number of markers \bar{m} was found, which should have fallen in each point sample. According to the Poisson formula, the theoretical values of T distributions are found. The distributions are presented in Table 1.

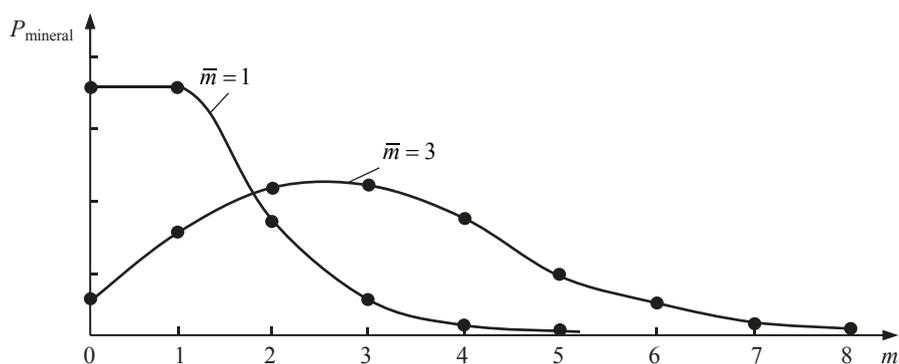


Figure 4. Calculated distributions of the mass fraction for $\bar{m} = 1$ and $\bar{m} = 3$
Рисунок 4. Расчетные распределения массовой доли для $\bar{m} = 1$ и $\bar{m} = 3$

Experimental estimates. The distributions shown are fundamental to understanding the results of sampling. In particular, point samples (including sample weights for analysis) are fundamentally different: one sample differs from another in the valuable component mass fraction, and in some cases the difference is significant. It can be seen from Table 1 that among the point samples that are identical in terms of sampling technology, there can be individual samples that do not contain a single marker. There can also be samples containing 2–3 markers or more.

The second experimentally confirmed conclusion is that the valuable component mass fraction distributions in point samples are fundamentally asymmetric and it makes no sense to check them for normality.

The valuable component mass fraction distribution in point samples (sample weights) was experimentally determined for a mixture of quartz with a particle size of -0.1 mm and iron sawdust with a particle size of $-0.2+0.1$ mm in paper [10]. The average mass fraction of sawdust was 0.02% (0.2 g of sawdust per 1,000 g of quartz). Reducing the mixed sample by squaring (80 micro-portions) and with a 200 cm long ruler (240 micro-portions) revealed that in ten parallel sample weights, the deviations in sawdust mass fractions reach 70% (rel.).

To experimentally determine the values of \bar{d}_{grain} and b , three classes of ore size were distinguished. In each grain size class, 100–200 lumps were collected. The valuable component mass fraction in each lump was analyzed. After that, the experimental value of the lump dispersion was determined for each j -th size class $S_{\text{lump}}^2(\bar{d}_j)$. The lump dispersion was subsequently calculated for the released ore $S_{\text{lump}}^2(0)$. Afterwards, the obtained values of S_{lump}^2 for classes with average lump sizes of pieces \bar{d}_1, \bar{d}_2

and \bar{d}_3 were plotted on the graph (Figure 5). A curve was drawn through the points corresponding to the indicated values. A horizontal line is drawn through the point $S_{lump}^2(0)$ until it intersects curve $S_{lump}^2(\bar{d}_j)$. The point of their intersection corresponds to the average grain size \bar{d}_{grain} .

The formula for b is proposed:

$$b = 3 - \frac{\lg S_{lump}^2(0) - \lg S_{lump}^2(\bar{d}_2)}{\lg \bar{d}_2 - \lg \bar{d}_3}$$

Experimentally found values \bar{d}_{grain} and b can be accepted as average for the ore under consideration.

Table 1. Experimental and theoretical distributions of markers in the composition of an artificial mixture

Таблица 1. Экспериментальные и теоретические распределения маркеров в составе искусственной смеси

Average number of markers	Point sample mass, g	Distributions	Number of markers m in point samples					
			0	1	2	3	4	5
$\bar{m} = 0.4$	80	E	0.63	0.31	0.058	0	0	0
		T	0.67	0.27	0.054	0.007	0	0
$\bar{m} = 0.63$	100	E	0.53	0.33	0.100	0.030	0	0
		T	0.53	0.33	0.110	0.020	0.003	0
$\bar{m} = 0.9$	120	E	0.41	0.39	0.140	0.046	0.008	0
		T	0.39	0.37	0.170	0.053	0.012	0.002
$\bar{m} = 1.5$	140	E	0.22	0.33	0.270	0.140	0.031	0.016
		T	0.22	0.34	0.250	0.130	0.047	0.014

The size of \bar{d}_{grain} and the value of b were experimentally estimated for asbestos ore lumps with a laminated texture. In asbestos ore samples with a size of –6 mm, three grain-size classes were distinguished: –6+3, –3+1.4, and –1.4+0.5 mm. Two hundred lumps were selected from each grain-size class. In each piece, the asbestos fiber mass fraction value was estimated and lump dispersions were calculated. The experiment was performed 25 times. The dependence between the lump dispersion and grain size was built based on the results. It was found that the average grain size in the experiment \bar{d}_{grain} (the thickness of asbestos layers) is 0.43 mm, and the average b is 2.36, which is close to the expected value of b for laminated ores.

Results and discussion. Valuable component mass fraction distributions in concentrate point samples are fundamentally asymmetric. This is due to unequal amount of valuable mineral and rock lumps. For the only stable distribution of the mass fraction (under lump sampling), the fundamental formula for lump dispersion has been obtained. Provided that the number of a valuable mineral lumps in a sample is small, a mass fraction distribution following the Poisson law is obtained for quarter samples.

Theoretical and experimentally obtained mass fraction distributions were compared. The comparison showed their insignificant difference (verified according to the χ^2 -criterion).

The lump dispersion for aggregates depends on the texture of aggregates (indicator b) the size of mineral inclusions (d_{grain} size). A method for experimental determination of b

and d_{grain} was proposed. It was used for asbestos ore with a laminated texture. A value of $b = 2.36$ was obtained, corresponding to laminated ore.

Methods for sampling, calculating and analyzing performance indicators at preparation plants have been developed in accordance with domestic and international standards, in particular: GOST 14180-80 “Ores and concentrates of non-ferrous metals. Methods of sampling and preparation of samples for chemical analysis and determination of moisture”. The domestic standard GOST 14180-80 corresponds to the international standard ISO 12743:2018 “Copper, lead, zinc and nickel concentrates – Sampling procedures for determination of metal and moisture content” and its supplements for experimental methods of error determination ISO 12744:2006 (E) “Copper, lead, zinc and nickel concentrates – Experimental methods for checking the precision of sampling”,

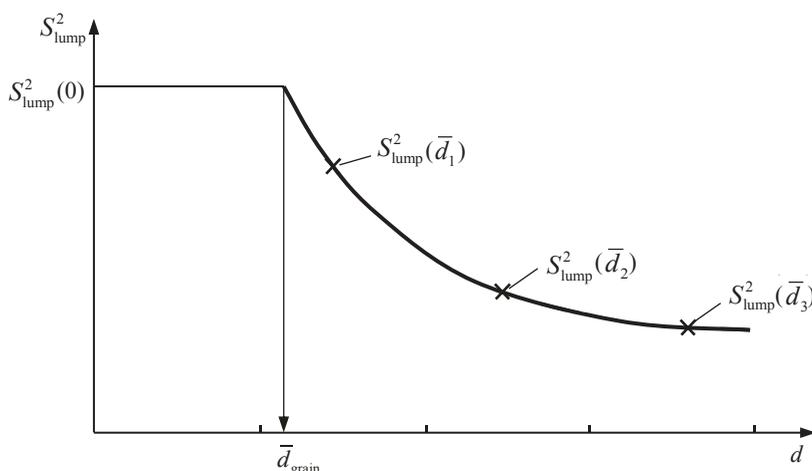


Figure 5. A graph for the experimental determination of \bar{d}_{grain} and b

Рисунок 5. График к экспериментальному определению величин \bar{d}_{grain} и b

ISO 13292:2006 (E) “Copper, lead, zinc and nickel concentrates – Experimental methods for checking the bias of sampling”. The sampling methods developed on their basis, in turn, provide for random error reduction and, therefore, normal distribution of desired component mass fractions in concentrates. Sophisticated [11, 12] and simplified [13] calculations in sampling based on the mass fraction distribution normality do not result in the resolution of problems associated with asymmetric distributions. Only a detailed account of the asymmetry results in real assessments of the situation [14]. The development of automatic and mechanized control and sampling systems provides support to this conclusion [15].

In the practices of preparation plants, the asymmetry of distributions manifests itself in the appearance of hurricane samples [16] and large positive product balances [17], as well as in a noticeable number of parallel analyses, where the difference in the valuable component mass fractions is beyond the permissible limits [18, 19]. Such events should be considered in methods and standards for testing the asymmetry of valuable component mass fractions distributions in concentrates. Paper [19] was among the first to propose in this direction, but since it was associated only with the distribution of permissible values of random errors, it did not reflect a more complex relationship between the asymmetry of mass fraction distributions and the performance of preparation plants [21].

This paper shows that the asymmetry of valuable component mass fractions distributions in concentrates is a mass phenomenon. It should be assessed and considered in sampling procedures development and in preparation plants practice in general.

Conclusions. The distributions of valuable component mass fraction in the point samples collected from the tested rock mass are always asymmetric. The asymmetry is the greater, the smaller the point sample mass and the barer (or richer) the samples product.

Low-grade products (ore, tailings) are characterized by right asymmetry, while high-grade products (concentrates) are characterized by left asymmetry. Valuable component mass fraction distributions in point samples for a particular tested rock mass change as point sample masses change. Mass fraction distributions that differ greatly from each other can therefore be obtained within one rock mass. The only stable form of valuable component mass fraction distributions is the distribution for the released material. Such a distribution is the main fundamental characteristic of any tested mass.

The fundamental numerical characteristic of the tested rock mass is the lump dispersion. The lump dispersion can be found analytically. The density of the mineral and rock ρ_{mineral} and ρ_{rock} are required, as well as the mass fraction of the component in the ore α and the mass fraction of the component in the mineral β_{mineral} . The size of the lumps a and grains of the useful material \bar{d}_{grain} , as well as the value of mineral dissemination characteristic b are also required.

For released products, it is experimentally shown that the experimental distributions coincide with the theoretical distributions calculated by the Poisson distribution formula. For aggregates, an experimental method for determining the value of \bar{d}_{grain} and b is proposed. For asbestos ore with a laminated texture, values $\bar{d}_{\text{grain}} = 0.43$ mm and $b = 2.36$ are obtained.

REFERENCES

1. Engström K., Esbensen K. H. Evaluation of sampling systems in iron concentrating and pelletizing processes – Quantification of Total Sampling Error (TSE) vs. process variation. *Minerals Engineering*. 116; 15 January 2018: 203–208. Available from: doi: 10.1016/j.mineng.2017.07.008
2. Lotter N. O., Evans C. L., Engstom K. Sampling – A key tool in modern process mineralogy. *Minerals Engineering*. 2018; 116: 196–202.
3. Napier-Munn T. J., Whiten W. J., Faramarzi F. Bias in manual Sampling of rock particles. *Minerals Engineering*. 2020; 153: art. 106260.
4. Stupakova E. V. Measuring errors in the compositional reference materials of gold ore. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = News of the Higher Institutions. Mining Journal*. 2019; 6: 81–89. (In Russ.)
5. Nikitenko E. M., Evtushenko M. B., Iushina T. I. Improving the assay test for the Degdekan deposit ores. *Obogashchenie rud = Mineral Processing*. 2019; 1: 34–38. (In Russ.)
6. Bogatskii V. V. The effect of sample quality and size on mineral exploration results accuracy. In: *Issues of ore deposits testing in the course of exploration and exploitation*. Moscow: Gosgeoltekhizdat Publishing; 1962. (In Russ.)
7. Fomin Ia. I. Manganese and phosphorus distribution in the Nikopol basin ore. *Obogashchenie rud = Mineral Processing*. 1965; 2: 10–17. (In Russ.)
8. Karpenko N. V., Golubeva G. P., Sakharnikov V. N. On the law of high-grade metal content probability distribution in ores and concentrates. *Obogashchenie rud = Mineral Processing*. 1984; 1: 44–47. (In Russ.)
9. Lokonov M. F. *Sampling at preparation plants*. Moscow: Gosgortekhzdat Publishing; 1961. (In Russ.)
10. Lokonov M. F., Petrova M. I., Reingardt E. P. The procedure of preparing for assaying the samples of ore that contains platinum intermetallic compounds. *Obogashchenie rud = Mineral Processing*. 1984; 1: 44–47. (In Russ.)
11. Gleeson D. Getting to the core. *International Mining*. 2019; February: 64–68.
12. Garifulin I. F., Vidutskii M. G., Maltsev V. A., Purgin A. P. Complex mineral dressing circuit design. *Gornyi zhurnal = Mining Journal*. 2021; 10: 87–91.
13. Moore P. Making of elementary. *International Mining*. 2018; February: 10–17.
14. Rozendal A., Le Rous S. G., du Plessis A., Philander C. Grade and product quality control by microCT scanning of the world class Namakwa Sands Ti-Zr placer deposit West Coast, South Africa: An orientation study. *Minerals Engineering*, 2018; 116: 152–162.
15. Voituk I. N., Ivanchenko D. I., Khomiakov K. A. Hardware and software systems for rock quality control on conveyor belt. *Gornyi zhurnal = Mining Journal*. 2020; 5: 67–71. (In Russ.)
16. Kozin V. Z., Komlev A. S. Outstanding samples and their consideration. *Obogashchenie rud = Mineral Processing*. 2015; 4: 39–43. (In Russ.)

17. Kozin V. Z., Vodovozov K. A. Factors causing positive product imbalance at ore-dressing plants. *Obogashchenie rud = Mineral Processing*. 2013; 2: 27–31. (In Russ.)

18. Kavchik B. K. Optimal scheme of sample processing to reduce the work labour input and increase the efficiency of exploration. *Zolotodobycha = Gold mining*. 2020; 8(261): 42–43. (In Russ.)

19. Kavchik B. K. Optimal scheme of sample processing to reduce the complexity of work and increase the efficiency of exploration. *Zolotodobycha = Gold mining*. 2021; 1(266): 40–41. (In Russ.)

20. Karpenko N. V. Ore concentrates sampling and quality control. Moscow: Nedra Publishing; 1987. (In Russ.)

21. Komlev A. S. Preparing and using the product balance sheet of a preparation plant. *Gornyi informatsionno-analiticheskii biulleten (nauchno-tekhnicheskii zhurnal) = Mining Informational and Analytical Bulletin (scientific and technical journal)*. 2021; 11–1: 276–284. (In Russ.)

Received 20 May 2022

Information about the authors:

Vladimir Z. Kozin – DSc (Engineering), Professor, Head of Mineral Processing Department, Dean of the Mining Machinery Faculty, Ural State Mining University. E-mail: gmf.dek@ursmu.ru; <https://orcid.org/0000-0001-7184-919X>

Aleksei S. Komlev – PhD (Engineering), senior researcher of Mineral Processing Department, Ural State Mining University. E-mail: tails2002@inbox.ru; <https://orcid.org/0000-0002-2484-2726>

УДК 622.7.09:620.113

DOI: 10.21440/0536-1028-2022-5-77-87

Асимметрия распределений массовой доли определяемого компонента в точечных пробах

Козин В. З.¹, Комлев А. С.¹

¹ Уральский государственный горный университет, Екатеринбург, Россия.

Реферат

Введение. Распределения массовой доли определяемых компонентов в точечных пробах на обогатительных фабриках асимметричны. Причиной асимметрии является природная гетерогенность руд.

Теория асимметричности распределения массовых долей в пробах. В основе теории лежит покусковой отбор точечных проб. Распределения массовых долей при таком отборе состоят из двух разновеликих долей – полезного минерала и породы. Эти распределения всегда асимметричны. Покусковая дисперсия для асимметричных распределений зависит от массовой доли полезного минерала как для раскрытых зерен, так и для сростков с породой. Распределение массовой доли в точечных пробах бедных по массовой доле продуктов описывается формулой Пуассона.

Материалы и методы. Экспериментальное подтверждение соответствия распределений массовой доли формуле Пуассона выполнено на искусственном опробуемом массиве, представленном кварцевой крупкой с цветными маркерами. От массива отбирались точечные пробы разной массы.

Экспериментальные оценки. Распределения, полученные экспериментальным путем, совпали с распределениями, рассчитанными по формуле Пуассона. Предложена методика экспериментального определения среднего размера зерен полезного минерала и показателя текстуры руды, иллюстрированная определением указанных величин для асбестовой руды.

Обсуждение результатов. Асимметричность распределений массовых долей в точечных пробах не учитывается в стандартах на опробование. В практике работы обогатительных фабрик она проявляется в появлении ураганных проб, а также положительных невязок товарных балансов, в расхождении результатов анализов параллельных навесок, превышающих допустимые пределы. Асимметрию распределений массовых долей компонентов в продуктах обогащения следует учитывать в стандартах и методиках на опробование, а также в целом в практике работы обогатительных фабрик.

Ключевые слова: точечные пробы; распределение массовых долей; асимметрия распределений; покусковое опробование; средний размер зерен; показатель текстуры руды.

БИБЛИОГРАФИЧЕСКИЙ СПИСОК

1. Engström K., Esbensen K. H. Evaluation of sampling systems in iron concentrating and pelletizing processes – Quantification of Total Sampling Error (TSE) vs. process variation // *Minerals Engineering*. 2018. Vol. 116. P. 203–208. DOI: 10.1016/j.mineng.2017.07.008

2. Lotter N. O., Evans C. L., Engstrom K. Sampling – a key tool in modern process mineralogy // Minerals Engineering. 2018. Vol. 116. P. 196–202.
3. Napier-Munn T. J., Whiten W. J., Faramarzi F. Bias in manual Sampling of rock particles // Minerals Engineering. 2020. Vol. 153. Art. 106260.
4. Ступакова Е. В. Определение погрешностей стандартных образцов состава золотосодержащих руд // Известия вузов. Горный журнал. 2019. № 6. С. 136–143.
5. Никитенко Е. М., Евтушенко М. Б., Юшина Т. И. Совершенствование пробирного анализа руд Дегдеканского месторождения // Обогащение руд. 2019. № 1. С. 34–38.
6. Богацкий В. В. Влияние качества и размера проб на точность результатов разведки полезных ископаемых // Вопросы опробования рудных месторождений при разведке и эксплуатации. М.: Госгеолтехиздат, 1962. С. 16–27.
7. Фомин Я. И. Распределение марганца и фосфора в рудах Никопольского бассейна // Обогащение руд. 1965. № 2. С. 10–17.
8. Карпенко Н. В., Голубева Г. П., Сахарников В. Н. О законе распределения вероятностей содержания благородных металлов в рудах и продуктах обогащения // Обогащение руд. 1984. № 1. С. 44–47.
9. Локонов М. Ф. Опробование на обогатительных фабриках. М.: Госгортехиздат, 1961. 276 с.
10. Локонов М. Ф., Петрова М. И., Рейнгардт Е. П. Методика подготовки для анализа проб руды, содержащей интерметаллические соединения платиновых металлов // Обогащение руд. 1971. № 2. С. 43–47.
11. Gleeson D. Getting to the core // International Mining. February 2019. P. 64–68.
12. Гарифулин И. Ф., Видуцкий М. Г., Мальцев В. А., Пургин А. П. О расчете сложных схем обогащения минерального сырья // Горный журнал. 2021. № 10. С. 87–91.
13. Moore P. Making of elementary // International Mining. February 2018. P. 10–17.
14. Rozendal A., Le Rous S. G., du Plessis A., Philander C. Grade and product quality control by microCT scanning of the world class Namakwa Sands Ti-Zr placer deposit West Coast, South Africa: an orientation study // Minerals Engineering. 2018. Vol. 116. P. 152–162.
15. Войтюк И. Н., Иванченко Д. И., Хомяков К. А. Аппаратно-программный комплекс контроля качества горной массы на ленточном конвейере // Горный журнал. 2020. № 5. С. 67–71.
16. Козин В. З., Комлев А. С. Ураганные пробы и их учет // Обогащение руд. 2015. № 4. С. 39–43.
17. Козин В. З., Водовозов К. А. Причины положительных невязок товарного баланса на обогатительных фабриках // Обогащение руд. 2013. № 2. С. 27–31.
18. Кавчик Б. К. Оптимальная схема обработки проб для сокращения трудоемкости работ и повышения эффективности разведки // Золотодобыча. 2020. № 8(261). С. 42–43.
19. Кавчик Б. К. Оптимальная схема обработки проб для сокращения трудоемкости работ и повышения эффективности разведки // Золотодобыча. 2021. № 1(266). С. 40–41.
20. Карпенко Н. В. Опробование и контроль качества продуктов обогащения руд. М.: Недра, 1987. 215 с.
21. Комлев А. С. Составление и использование товарного баланса обогатительной фабрики // ГИАБ. 2021. № 11-1. С. 276–284.

Поступила в редакцию 20 мая 2022 года

Сведения об авторах:

Козин Владимир Зиновьевич – доктор технических наук, профессор, заведующий кафедрой обогащения полезных ископаемых, декан горно-механического факультета Уральского государственного горного университета. E-mail: gmf.dek@ursmu.ru; <https://orcid.org/0000-0001-7184-919X>

Комлев Алексей Сергеевич – кандидат технических наук, старший научный сотрудник кафедры обогащения полезных ископаемых Уральского государственного горного университета. E-mail: tails2002@inbox.ru; <https://orcid.org/0000-0002-2484-2726>

Для цитирования: Козин В. З., Комлев А. С. Асимметрия распределений массовой доли определяемого компонента в точечных пробах // Известия вузов. Горный журнал. 2022. № 5. С. 77–87 (In Eng.). DOI: 10.21440/0536-1028-2022-5-77-87

For citation: Kozin V. Z., Komlev A. S. Asymmetric distributions of desired component mass fraction in point samples. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = Minerals and Mining Engineering*. 2022; 5: 77–87. DOI: 10.21440/0536-1028-2022-5-77-87