# Converting of copper-lead matte: loss of gold and silver with slag

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**Abstract.** Based on comprehensive studies, including methods of elemental, X-ray phase analysis and mineralogical studies of solid slag and dust samples, quantitative ratios of the forms of finding copper, lead and precious metals are determined, a mechanism for the distribution of gold and silver between converting products is established. It is shown that the loss of gold and silver under the conditions of converting of copper-lead matte is associated with their redistribution between converter slag and dust. It was established that the loss of gold with converter slag and dust is determined by the content of mechanical losses of copper in them. Loss of silver in the slag is determined by the content of lead in them. As a result of mathematical processing of the compositions of the converting products, the regression equation of pair correlation is constructed, which describes the dependence of the gold loss in slag on the mechanical loss of copper in it with a high correlation coefficient (r = 0.92). An increase in mechanical losses of copper in slag from 0.5 to 0.95% leads to an increase in the gold content in slag by more than 1.5 times. An increase in the copper content in the form of sulfide in dust from 1.5 to 3% increases the gold content in dust from 2 to 7%. Unlike gold, silver is highly correlated with lead. An increase in the content of lead in slag from 17 to 25% increases the silver content in it from 100 to 150 g / t. It is shown that in the process of converting copper-lead matte, it is necessary to provide measures to minimize losses of copper and lead in slag, which will reduce the gold and silver contents in them and significantly increase their extraction into blister copper. To reduce the loss of gold, a solution is necessary on the one hand, the task of reducing the mechanical loss of copper with slag, and on the other, minimizing dust removal under conditions of converting copper-lead mattes.
**Keywords:** copper-lead matte, slag, dust, metal loss, extraction, copper, gold, silver.

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## Introduction

Since copper is the second functional metal after iron, the copper production process has an important value. The most common method for the production of copper is the pyrometallurgical treatment of

sulfide concentrates in two stages: the first one is the smelting operation where copper matte is obtained, and then the second one is the processing of matte by converting to produce blister copper. Almost all

metallurgical plants producing copper, as well as lead, consider processing of mattes in Pierce-Smith converters.

The theory and practice of converting of copper matte is well established and is described in detail in the scientific literature [1, 2, 3]. Nevertheless, despite the extensive theoretical material [4, 5, 6], the issues of the behavior of gold and silver as well as the studies of the causes and factors affecting their extraction into blister copper remain to be further investigated. The study of this issue has an exceptional interest from the point of view of the complexity of the use of raw materials [7] and increasing the extraction of precious metals into the final product. This shows a great interest in studying of the issue particularly related to the process of converting of copper-lead mattes obtained in lead production [8, 9].

A distinctive feature of lead mattes obtained by KazZinc Ltd. in the processes of mine reduction and mine contractile smelting is elevated lead content up to 30 (wt.)% [10]. The high concentration of lead in mattes has a significant effect on the behavior of precious metals in the converting process. It is clearly seen from the results of industrial data: an increase in the lead content in converter slags to 35% leads to an increase in the concentration of silver and gold in slag to 200 and ~ 1.0 g/t, respectively. The circulation of converter slag in the "smelting - converting" chain leads to an increase not only in the total losses of lead, but also in precious metals due to their "smearing" between the smelting products [11].

It is noted that the integration of lead with gold and silver is not entirely unambiguous as it is considered in metallurgy. This is especially pronounced for reduction smelting with the production of copper-lead matte. In article [12], it was established that the losses of gold with slag in the conditions of mine contractile smelting of lead intermediate products and recycled materials does not depend on the lead content in matte and slag. An increase in the losses of gold with slag is accompanied by an increase in the mechanical losses of copper in the slag. Under oxidizing conditions of converting even greater increase in the mechanical losses of copper with slag is expected due to the increased content of magnetite in it. Therefore, the study of the behavior of gold in the process of converting of copper-lead matte depending on the mechanical losses of copper with converter slag requires additional research. According to our view, creating conditions for deep sublimation of lead and reducing losses of lead and copper with slag will significantly increase the extraction of gold and silver into blister copper. The relevance of the study of this issue is enhanced by the fact that a significant concentration of lead and copper in dust (including the sulfide form of copper) leads to an increase in the losses of gold and silver with dust as well, reducing their overall extraction into blister copper.

The purpose of this work is to study the mechanism of losses of gold and silver with converter slag and dust under conditions of converting of copper-lead mattes.

## Methods of conducting technological experiments

From the theory and practice of converting copper mattes it is known that the main factors affecting the distribution of non-ferrous, noble and related metal impurities between the conversion products are their matte content, slag composition, matte metallization and temperature. Acting in conjunction, these factors determine a very complex picture of the transition of non-ferrous metals to slag. It is impossible to quantitatively describe this whole set, not only theoretically, but also statistically, according to factory data. When conducting statistical analysis, significant difficulties arise due to the lack of factory data. Thus, in KazZinc Ltd, in the process of converting copper-lead mattes in shift slag analyzes, the content of copper, noble and related metal impurities (As, Sb, Pb) is not determined. Given these shortcomings, in the experimental part of the work, first of all, the task was to identify the influence of the most significant factors on the distribution of non-ferrous and noble metals between conversion products, to determine the most important dependencies characterizing their losses, and to construct the corresponding statistical dependencies.

During this stage of the work, the main attention was paid to the analysis of these conversion products - copper-lead matte, converter slag and dust. For this, the results of monthly factory analyzes of matte, slag and dust samples were taken and comprehensive studies were carried out to determine the total elemental composition of the samples. In total, data from 65 samples were processed, which is quite enough to identify significant dependencies.

Comprehensive studies of sample compositions included the X-ray spectral microanalysis method using a Super Probe 733 electron probe microanalysis (Jeol, Japan). In order to increase the reliability of the results and evaluate the statistical analysis, the elemental composition of matte, converter slag and dust samples was additionally studied using an Agilent 7700 Series ICP-MS inductively coupled plasma mass spectrometer.

Additional mineralogical studies on the surface structure of solid air-hardened matte and slag samples were carried out using a Neofot microscope (Carl Zeiss AG, Germany). Micro and morphological analysis of the surface of individual slag samples was

carried out using a JEOL EDS System (USA) electron scanning microscope.

X-ray diffractometric analysis was carried out on a Cu Ka - radiation, β-filter. Conditions for recording diffractograms: U = 35 kV; I = 20 mA; θ-2θ survey; detector 2 deg / min.

### Results and discussion

Converting of copper-lead matte at KazZinc Ltd. is carried out in 12-ton converters with the addition of quartz flux containing 65% $SiO_2$. Flux consumption is 2 tons per ton of produced blister copper. The converter is equipped with 10 tuyeres with a diameter of d=38 mm to supply air blast. Air consumption is 7.5 thousand $m^3$/h.

Around 60 tons of matte per day are processed in the converting stage with incomplete loading of production capacities. The blister copper obtained during converting corresponds to the BLC-1 grade (Cu - not less than 95%; Pb - not more than 2%) and BLC-2 grade (Cu - not less than 90%; Pb - not more than 4%) and is regulated by the requirement of CT AO 30884350-004-2007.

As the results of article [8], it indicates that the distribution coefficient of copper varies widely - from 25 to 45, depending on the variation of its content in matte in the range from 30 to 45%. The final lead content in blister copper is strongly correlated with the content of non-ferrous metals in the matte: under converting conditions, the lead content in blister copper decreases with an increase in the total content of non-ferrous metals in matte.

Taking into account that the process of converting of copper-lead matte is carried out without adding any cold additives, a significant influence of the composition of the matte, in particular the content of copper and lead, on the distribution of gold and silver between the converting products should be considered. It was established in article [12] that the losses of gold with slag under the conditions of mine contractile smelting is mainly determined by the part of mechanical losses of copper in the slag. Moreover, the more mechanical losses of copper with slag, the greater the losses of gold with it. At the same time, it was shown that an increase in the content of lead in slags only slightly affects the loss of gold with slag. The lead content in the slag shows a close direct relationship exclusively with the silver content in the slag. Therefore, it can be assumed that the main indicator determining the losses of gold with converter slag and dust is the proportion of mechanical losses of copper in them, and the losses of silver is determined by the content of lead in these products. To check the offered approaches, the samples of converter slags and dust were subjected to X-ray phase and elemental analysis methods as well as mineralogical studies. 12 samples of converter slag and dust were examined. The phase composition of the converter slag and dust showed good constant regardless of fluctuations in the content of copper, lead, gold and silver in them. The results of a semiquantitative X-ray phase analysis of converter slag and dust samples are shown in Tables 1 and 2.

**Table 1** – Results of semi-quantitative analysis of converter slag

| Name of the phase | Formula | Composition, % |
|---|---|---|
| Chalcosine | $Cu_2S$ | 0.73 |
| Copper oxide | $Cu_2O$ | 4.41 |
| Intermetallic compounds | $Cu_3(As, Sb)$ | 1.11 |
| Lead oxide | PbO | 23.84 |
| Zinc oxide | ZnO | 3.14 |
| Fayalit | $Fe_2SiO4$ | 41.97 |
| Magnetite | $Fe_3O_4$ | 4.41 |
| Arsenic oxide | $As_2O_5$ | 2.15 |
| Antimony oxide | $Sb_2O_5$ | 0.3 |

**Table 2** – Results of semi-quantitative analysis of converter dust

| Name of the phase | Formula | Composition, % |
|---|---|---|
| Lead sulphate | $PbSO_4$ | 31.06 |
| Lead oxide | PbO | 23.71 |
| Chalcosine | $Cu_2S$ | 5.38 |
| Copper oxide | $Cu_2O$ | 0.21 |
| Sphalerite | ZnS | 5.04 |
| Iron oxide | FeO | 0.9 |
| Arsenic oxide | $As_2O_3$ | 15.28 |
| Antimony oxide | $Sb_2O_3$ | 9.56 |
| Silica | $SiO_2$ | 2.32 |
| Calcium oxide | CaO | 1.23 |

Mineralogical studies of solid samples of converter slag showed the predominant presence of copper in their oxide form (~85%). The proportion of copper identified as a mechanical suspension of matte is ~11.5%. Insignificant amounts of intermetallic compounds of copper with arsenic and antimony as well as ferrites were found.

Lead was found mainly in the form of oxide bound to quartz in silicate and in small amounts in the form of dissolved metal and sulfide, which is in good agreement with the data of work [15].

Lead was found mainly in the form of oxide bound to quartz as silicate. Lead in the form of dissolved metal was detected in negligible amounts. Arsenic is presented in the form of oxide ($As_2O_5$), which is associated with the silicate part of the slag. Antimony is represented in the form of its oxide ($Sb_2O_5$) and partially in metallic form ($Sb^o$). The results obtained are consistent with the data of [14, 15].

The main part of iron was found in the divalent ($Fe^{2+}$) form bound to fayalite (~78%). The part of ferric iron ($Fe^{3+}$) in the form of magnetite is ~ 5%. Also intermetallic compounds of iron with antimony, ferrites and a small proportion of iron sulfide were found.

Lead in converter dust is represented mainly by sulfate (55.61%) and oxide (43%). The proportion of sulfide component of copper in dust is ~80%, oxide - 16.3% of the total copper content in dust. The presence of a significant part of copper in dust in the form of a mechanical suspension of sulfides is a source of gold losses with dust.

The obtained results of the elemental composition of converter slag and dust by calculating their rational composition, taking into account the data of semi-quantitative X-ray phase analysis and mineralogical studies, showed good agreement with each other and with the results of direct determination of the elemental composition by using Super Probe 733 and an Agilent 7700 mass spectrometer.

Table 3 shows a sample array of the elemental composition of the studied converting products.

**Table 3** – Elemental composition of sample array of converting products

| Products | Composition of metals, (wt.)% | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cu | Pb | Zn | Fe | As | Sb | S | CaO | SiO₂ | [Au], g/t | [Ag], g/t |
| Matte | 28.8 | 19.42 | 6.75 | 13.71 | 3.02 | 1.06 | 25.36 | - | - | 12.1 | 997 |
| | 28.19 | 19.76 | 6.84 | 12.8 | 2.8 | 1.02 | 25.85 | - | - | 12.7 | 1037 |
| | 36.93 | 24.09 | 4.95 | 9.96 | 3.22 | 1.93 | 18.36 | - | - | 25.8 | 1245 |
| | 35.8 | 28.76 | 4.24 | 7.87 | 4.02 | 1.75 | 17.15 | - | - | 28.2 | 1513 |
| | 40.41 | 29.66 | 2.96 | 5.62 | 5.94 | 2.62 | 12.2 | - | - | 35.8 | 1570 |
| | 42.97 | 26.42 | 4.13 | 8.88 | 3.91 | 1.54 | 10.8 | - | - | 24.07 | 1430 |
| Converter dust | 8.38 | 55.85 | 2.86 | 0.38 | 16.36 | 3.21 | 5.06 | 0.12 | 0.48 | 2.75 | 127.6 |
| | 8.23 | 52.75 | 3.2 | 0.29 | 11.89 | 3.25 | 5.12 | 0.15 | 0.52 | 2.8 | 121.5 |
| | 6.83 | 51.36 | 3.86 | 0.63 | 10.65 | 2.2 | 4.76 | 0.11 | 0.38 | 2.5 | 118.6 |
| | 7.76 | 50.12 | 3.54 | 0.7 | 12.35 | 2.25 | 4.88 | 0.13 | 0.32 | 2.46 | 115.2 |
| | 6.11 | 47.69 | 4.25 | 0.83 | 10.23 | 1.92 | 4.23 | 0.14 | 0.26 | 1.5 | 109.6 |
| | 5.13 | 46.13 | 4.32 | 0.9 | 9.48 | 1.89 | 4.2 | 0.15 | 0.25 | 1.58 | 100.9 |
| Converter slag | 7.12 | 23.65 | 1.56 | 17.78 | 1.6 | 0.34 | 0.15 | 1.22 | 20.17 | 2.50 | 125.35 |
| | 7.88 | 23.08 | 2.18 | 18.23 | 1.45 | 0.26 | 0.17 | 1.2 | 20.89 | 2.60 | 115.60 |
| | 6.45 | 20.09 | 3.89 | 21.58 | 1.31 | 0.2 | 0.14 | 0.85 | 18.48 | 2.35 | 108.65 |
| | 6.89 | 24.07 | 3.41 | 20.21 | 1.21 | 0.22 | 0.13 | 0.72 | 17.32 | 2.27 | 144.23 |
| | 5.55 | 17.1 | 4.42 | 22.36 | 1.15 | 0.11 | 0.11 | 0.45 | 16.32 | 1.72 | 100.50 |
| | 5.36 | 17.02 | 4.35 | 23.89 | 1.1 | 0.1 | 0.1 | 0.35 | 15.58 | 1.68 | 100.00 |
| Blister copper | 94.3 | 1.3 | - | - | 0.53 | 0.60 | - | - | - | 110.7 | 7751 |
| | 96.2 | 1.44 | - | - | 0.58 | 0.52 | - | - | - | 92.5 | 6975 |
| | 92.9 | 0.7 | - | - | 0.68 | 0.48 | - | - | - | 78.7 | 5851 |
| | 93.18 | 0.89 | - | - | 0.75 | 0.44 | - | - | - | 84.3 | 4791 |
| | 88.1 | 1.46 | - | - | 0.83 | 0.80 | - | - | - | 37.4 | 3328 |
| | 87.5 | 1.6 | - | - | 0.9 | 0.76 | - | - | - | 30.7 | 4710 |

The obtained data is well aligned with the results of article [8] and allow calculating the detailed material balance of the process of converting of copper-lead mattes taking into account the content of sulfur, gold, silver and slag-forming components in the converting products (Table 4).

The calculated values of copper extraction into blister copper are ~ 80%, which is associated with its losses with converter slag and dust, 15 and 5%, respectively. High extraction of lead into converter slag (57%) significantly reduces its total extraction into dust, which is only 42%.

In the framework of the copper and lead extractions, the indicators for the extraction of precious metals are not entirely favorable. The extraction of gold and silver into blister copper is ~ 92 and 94%, respectively. A significant part of the gold is lost with converter slag (gold recovery into slag - 6%). The recovery of silver to converter slag (~ 5%) is slightly less. Extraction of gold and silver into dust, constituting 2 and 1.3%, make negative impact to their total extraction into blister copper. Finding the way to reduce the loss of gold and silver with these products requires further research to identify the causes and nature of these losses.

A primary analysis of industrial data made it possible to establish that the gold content, both in the initial matte and in the converter slag, practically does not correlate with the lead content in them. It was not possible to establish its relationship with the total copper content in the converter slag as well. At the same time, as mentioned above, the gold losses in fayalite slags are determined by the content of mechanical losses of copper in the slag and are directly dependent on them [12].

Apparently, this pattern should also apply under the oxidizing conditions of the converting of copper-lead matte. It is known that the higher is iron content in matte [16], the higher is part of mechanical losses of copper in slag. At low concentrations of iron in matte, typical for copper-lead matte, with an increase of the copper content in matte, the increase of the sulfur content is expected, which leads to increased mechanical losses of copper in the slag. This statement is supported by the dependence shown in Fig. 1, where a high correlation coefficient, $r = 0.82$, characterizes a strong relationship between the considered values.

**Table 4** – Average material balance of the process of converting of copper lead mattes

| Name of the products | Q-ty, t. | % | Cu I | Cu II | Pb I | Pb II | Zn I | Zn II | As I | As II | Sb I | Sb II | Fe I | Fe II | S I | S II | SiO₂ I | SiO₂ II | CaO I | CaO II | Au g/t | Ag g/t |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Loaded:** | | | | | | | | | | | | | | | | | | | | | | |
| Matte | 60 | 83 | 35.3 | 21.18 | 25.9 | 15.54 | 3.4 | 2.04 | 3.8 | 2.28 | 0.7 | 0.42 | 15.15 | 9.09 | 15.08 | 9.05 | | | | | 24.05 | 1790.6 |
| Quartz Flux | 12 | 17 | | | | | | | | | | | 5.16 | 0.62 | | | 68.0 | 8.16 | 3.0 | 0.36 | | |
| **Total:** | 72 | 100 | | 21.18 | | 15.54 | | 2.04 | | 2.28 | | 0.42 | | 9.71 | | 9.05 | | 8.16 | | 0.36 | | |
| **Produced:** | | | | | | | | | | | | | | | | | | | | | | |
| Blister copper | 18 | 25 | 94.8 | 17.06 | 1.1 | 0.2 | n.d. | - | 0.9 | 0.16 | 0.6 | 0.11 | n.d. | - | n.d. | - | n.d. | - | n.d. | - | 73.61 | 5613 |
| Converter slag | 42 | 58 | 7.46 | 3.13 | 21.1 | 8.86 | 3.86 | 1.62 | 1.19 | 0.5 | 0.17 | 0.07 | 22.9 | 9.62 | 0.12 | 0.05 | 19.23 | 8.08 | 0.83 | 0.35 | 2.13 | 120.3 |
| Dust | 12 | 17 | 8.3 | 0.99 | 54 | 6.48 | 3.5 | 0.42 | 13.5 | 1.62 | 2.0 | 0.24 | 0.83 | 0.1 | 4.16 | 0.5 | 0.66 | 0.08 | 0.08 | 0.01 | 2.37 | 112.5 |
| **Total:** | 72 | 100 | | 21.18 | | 15.54 | | 2.04 | | 2.28 | | 0.42 | | 9.71 | | 9.05 | | 8.16 | | 0.36 | | |



$(S) = 0{,}001 + 0{,}004*[Cu],\ r = 0{,}84$
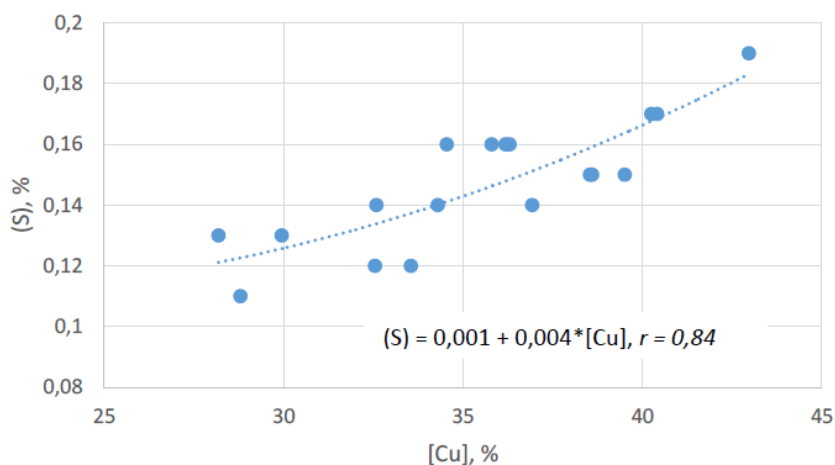
**Figure 1** - Change in the content of sulfur in converter slag from the content of copper in matte
Hereinafter, data from the general array corresponding
to minimum, average and maximum contents of copper in matte

The results of the elemental analysis of converter slags by sulfur content (Table 3), as well as XRD data (Tables 1, 2) and mineralogical studies, allowed to carry out calculations to determine the content of copper sulfide component ($Cu_2S$) in the slag for each point of the industrial array and analyze its connection with copper content in matte. Figure 2 shows the dependence of the content of the sulfide form of copper in the converter slag on the content of copper in matte: the mechanical losses of copper in the converter slag increase with increasing copper content in matte. A high correlation coefficient *(r = 0.93)* shows a close relationship and minimal scatter of data on the graph, which indicates a high reliability of the results and the accuracy of the calculations.

The adequacy of the dependence of gold content in the converter slag on the calculated value of the content of sulfide component of copper in the slag was checked to assess the losses of gold with converter slag. As a result of mathematical processing of a full array of industrial data, the regression equation of pair correlation is obtained, which describes the dependence *(Au) − f (Cu₂S)* with a high correlation coefficient (*r = 0.92*). A graphical view of the dependence is shown in Fig. 3. It is seen that the losses of gold with converter slag is determined by the mechanical losses of copper in the slag: an increase in the mechanical losses of copper in the slag from 0.5 to 0.95% leads to an increase in the gold content in the slag by more than 1.5 times. The result obtained is supported by the opinion of A.V. Vanyukov that the loss of gold with slag is determined mainly by the presence of a fraction of the mechanical loss of copper [16].

Using the above method, the sulfide component of copper in the converter dust was calculated and its relationship with the gold content in dust was analyzed. As in the case with converter slag, a direct dependence of the gold content with the content of the sulfide component of copper in dust was established (Fig. 4).

As can be seen in Fig. 5, unlike gold and silver, both in converter slag and in dust strongly correlates with the total lead content in them. This indicates the prevailing role of lead and supports the statement that lead is an active collector of silver, irrespective of its form in converting products.
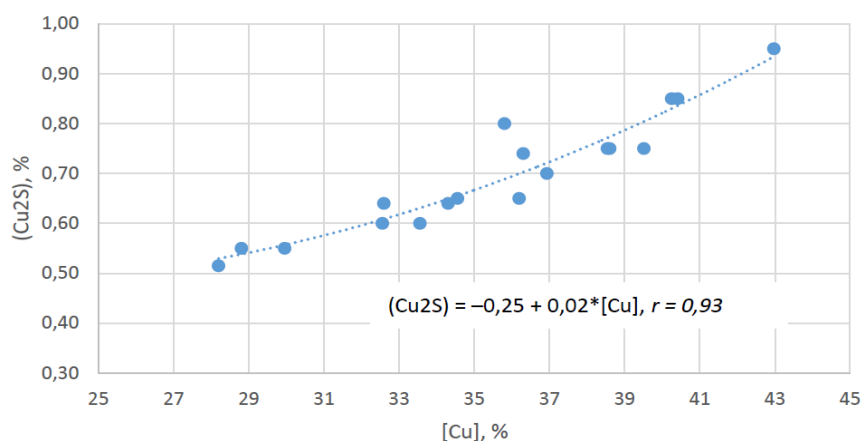


$$(Cu2S) = -0,25 + 0,02*[Cu], \ r = 0,93$$

**Figure 2** - Dependence of the content of mechanical losses of copper in converter slag on the content of copper in matte
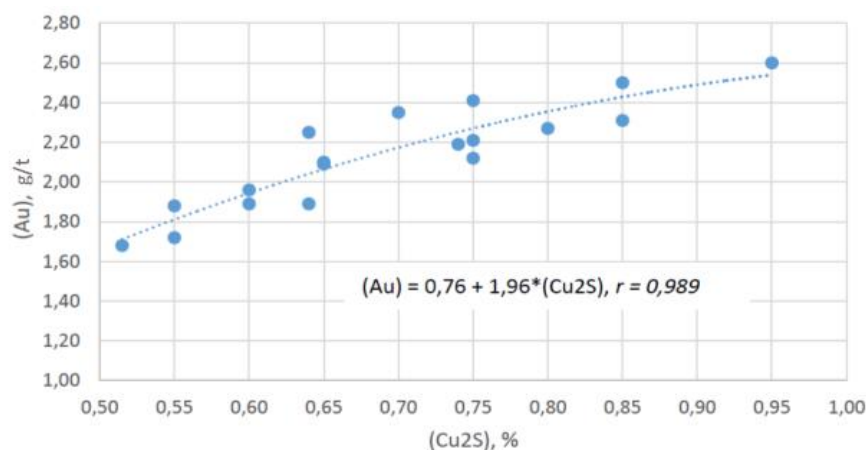


$$(Au) = 0,76 + 1,96*(Cu2S), \ r = 0,989$$

**Figure 3** - Dependence of the content of gold in converter slag from the content of copper sulfide in it
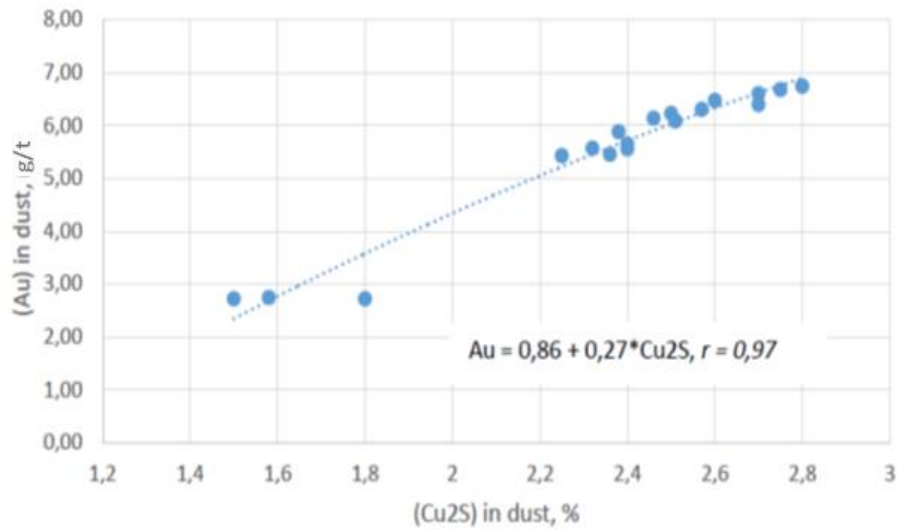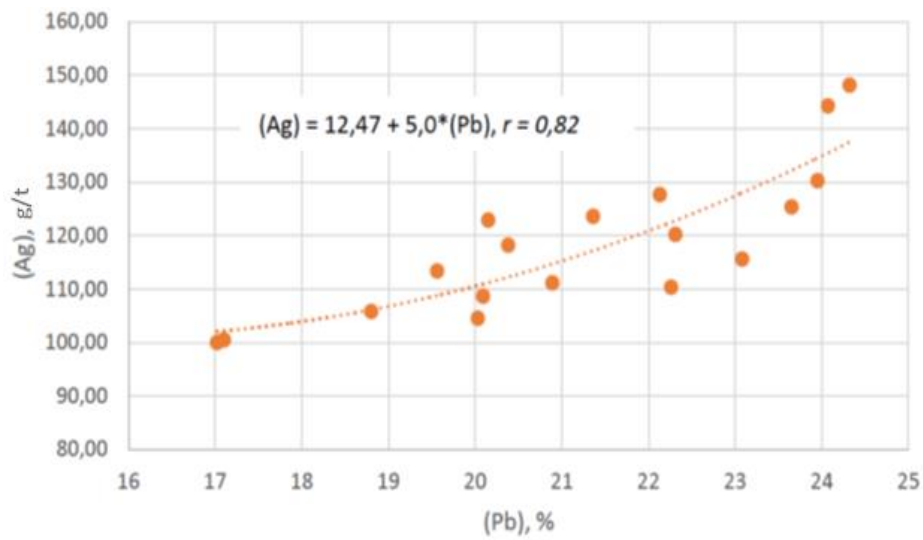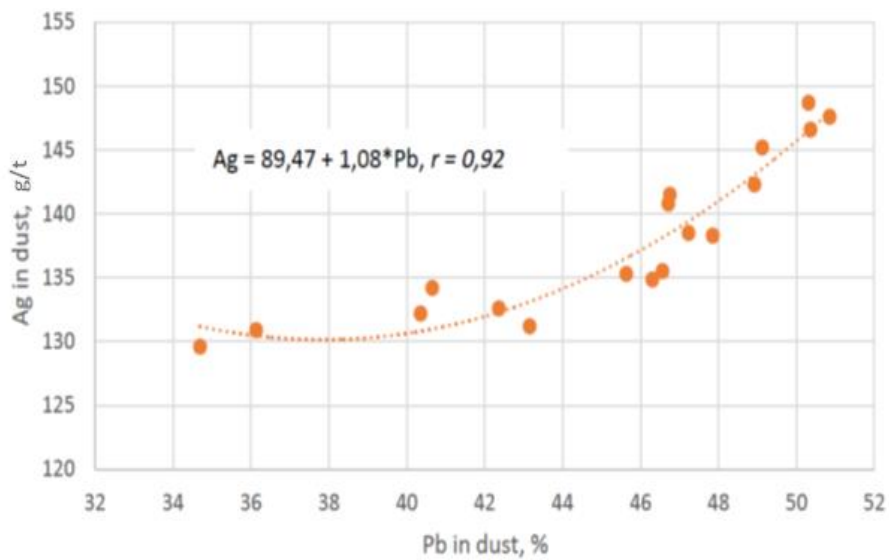
**Figure 4** - Dependence of the content of gold in the converter dust
from the content of copper sulfide in it



**(A)**



**(B)**

(A) - in converter slag; (B) - in converter dust

**Figure 5** - Dependence of the content of silver from the content of lead

Thus, the study results show that the loss of gold and silver in the conditions of converting of copper-lead matte are associated with their redistribution between converter slag and dust. Decrease in the lead content in the initial mattes can be considered as one of the conditions for optimizing the process of converting of copper-lead mattes. In cases where it is not possible to reduce the lead content in the obtained mattes, it is necessary to minimize the lead content in the converter slags. This leads to maximize the extraction of silver in blister copper. More complex solutions are required in order to reduce the losses of gold: solving the issue of reducing the mechanical losses of copper with slag, and on the other hand, minimizing the amount of flue dust under conditions of converting of copper-lead mattes.

## Conclusions

1. The mechanism for the distribution of gold and silver between converting products has been established based on the comprehensive studies, including the study of elemental and phase composition, the determination of the quantitative ratios of the forms of metals by mineralogical studies of converter slag and dust samples.

2. It was established that the losses of gold with converter slag and dust is determined by the content of mechanical losses of copper in them. It is necessary to consider measures to minimize losses of copper and lead in slag in order to reduce the losses of gold and silver in the process of converting of copper-lead mattes.

3. It is shown that the process of converting of copper-lead matte is accompanied by a large amount of flue dust. The increased copper content in dust in the form of a sulfide suspension (~ 12% of the total copper content in dust), even minor, but still is a source of gold losses with dust, contributing to a decrease in the total gold recovery into blister copper.

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## Мысты-қорғасынды штейндерді конвертерлеу: алтын мен күмістің шлакпен жоғалымы

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**Түйіндеме**. Шлак пен шаңның қатты сынамаларын элементтік талдауынан, рентгенді фазалық талдауынан және минералогиялық зерттеулерінен тұратын кешенді зерттеулердің негізінде мыс, қорғасын және асыл металдардың табылу түрлерінің сандық қатынасы, конвертерлеу өнімдерінің арасында алтын мен күмістің бөлініп таралу механизмі анықталынды. Мысты-қорғасынды штейнін конвертерлеу кезінде алтын мен күмістің жоғалуы олардың шлак пен шаң арасында қайта бөлініп таралуымен байланысты екендігі көрсетілген. Шлактармен және шаңдармен алтынның жоғалуы олардағы мыстың механикалық жоғалымымен байланысты екендігі орнатылды. Шлактағы күмістің жоғалымы ондағы қорғасынның мөлшерімен анықталады. Конвертерлеу өнімдерінің құрамын математикалық өңдеу нәтижесінде жұптық корреляциялық регрессия теңдеуі құрылды. Теңдеу шлактағы алтынның жоғалымын ондағы мыстың механикалық жоғалымына тәуелділігін жоғары корреляция коэффициентімен (r = 0.92) сипаттайды. Шлактағы мыстың механикалық жоғалымы 0,5-тен 0,95% -ға артуы шлакта алтынның 1,5 еседен астам өсуіне әкеледі. Шаңда мыстың сульфидті мөлшері 1,5-нан 3 %-ға дейін артқан кезде шаң құрамында алтынның мөлшері 2-ден 7%-ға дейін артады. Күміс қорғасынмен өте тығыз байланысты. Шлактағы қорғасынның мөлшері 17-ден 25% -ға дейін жоғарылауы оның құрамындағы күмістің мөлшерін 100-ден 150 г / т-қа дейін арттырады. Мыс-қорғасынды штейндерді конвертерлеу процесі кезінде мыс пен

қорғасынның шлакпен жоғалымын мейлінше азайту шараларын қарастыру қажет, бұл олардың құрамындағы алтын мен күмістің мөлшерін азайтады және қаралы мысқа бөліп алуын едәуір арттыруға мүмкіндік береді. Алтынның жоғалымын азайту үшін, бір жағынан, мыстың шлакпен механикалық жоғалымын азайту, екінші жағынан, мысты-қорғасынды штейндерінің конвертерлеу жағдайында шаңның шығымын азайту қажет.

**Түйін сөздер:** мысты-қорғасынды штейн, шлак, шаң, металдардың жоғалымдары, бөліп алу, мыс, алтын, күміс.

## Конвертирование медно-свинцовых штейнов: потери золота и серебра со шлаком

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**Аннотация.** На основании комплексных исследований, включающих методы элементного, рентгенофазового анализа и минералогического изучения твердых проб шлаков и пыли, определены количественные соотношения форм нахождения меди, свинца и благородных металлов, установлен механизм распределения золота и серебра между продуктами конвертирования. Показано, что потери золота и серебра в условиях конвертирования медно-свинцовых штейнов связаны с их перераспределением между конвертерным шлаком и пылью. Установлено, что потери золота с конвертерным шлаком и пылью определяются содержанием механических потерь меди в них. Потери серебра в шлаке определяются содержанием свинца в нем. В результате математической обработки составов продуктов конвертирования построено регрессионное уравнение парной корреляции, описывающая зависимость потери золота в шлаке от механических потерь меди в нем с высоким коэффициентом корреляции ($r = 0{,}92$). Рост механических потерь меди в шлаке с 0,5 до 0,95 % ведет к увеличению содержания золота в шлаке более чем в 1,5 раза. Увеличение содержания меди в виде сульфида в пыли с 1,5 до 3 % увеличивает содержание золота в пыли с 2 до 7%. В отличие от золота, серебро сильно корелировано с содержанием свинца. Рост содержания свинца в шлаке с 17 до 25 % повышает содержание серебра в нем от 100 до 150 г/т. Показано, что в процессе конвертирования медно-свинцовых штейнов необходимо предусмотреть меры по минимизации потерь меди и свинца в шлаках, что позволит снизить содержания золота и серебра в них и значительно повысит их извлечение в черновую медь. Для снижения потерь золота необходимо решение с одной стороны, задачи снижения механических потерь меди со шлаком, и с другой – обеспечение минимизации пылевыноса в условиях конвертирования медно-свинцовых штейнов.

**Ключевые слова:** медно-свинцовый штейн, шлак, пыль, потери металлов, извлечение, медь, золото, серебро.

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