

# Development of the Technology for Reduction of Magnetite from Slags of Copper Smelters and Improvement of Its Sulphidation Efficiency

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**Abstract**— *Uzbekistan is one of the countries with a highly developed metallurgical industry. The formation of this industry was facilitated by rich mineral resources and the availability of energy sources. In the bowels of Uzbekistan there are deposits of almost all elements of the periodic table, and many of these reserves are already in commercial exploitation. At present, the mining and metallurgical industry of the republic faces a whole range of complex problems. This is, first of all, the all-round depletion of rich and easily discovered ore deposits, increased requirements for environmental protection, and an increase in demand for non-ferrous metals, including copper and related elements. An urgent problem is to increase the complexity of the use of raw materials, the utilization of all valuable components, the development and implementation of low-waste technologies.*

**Keywords**— copper, slag, reduction, pyrite, gypsum, processing.

## INTRODUCTION

The waste and semi-products of the Almalyk Mining and Metallurgical Combine have accumulated a large amount of tailings from processing plants, copper production slag and clinker from the processing of zinc cakes. These materials contain non-ferrous, precious metals and are actually out of the production cycle. Involving them in processing will allow the plant to significantly expand the raw material base without increasing capital costs for geological and mining operations [1-3].

So, at present, over 1 billion tons of tailings from processing plants with a copper content of 0.07 - 0.112% have been accumulated in tailings. They contain over 800 thousand tons of copper, 10 thousand tons of molybdenum, 182 tons of rhenium, 500 thousand tons of zinc and many other valuable components [4].

More than 10 million tons of dump slags from reflective processing and oxygen-torch smelting have already been accumulated in the wastes of the pyrometallurgical production of copper. Even with an average copper content of about 0.6%, it can be calculated that more than 70 thousand tons of copper are not involved in the national economic turnover. More than 1000 tons of such slags are formed daily [5].

Tens of thousands of tons of solid converter slags, in which the copper content is 2.5 - 3.5%, have been accumulated in special storage facilities. In these slags, thousands of tons of valuable metal are unused. It should be especially noted that about 24,000 tons of such slags are additionally formed annually [6].

Clinker of zinc production contains over 2.2% copper, 2.4% zinc, 0.01% cadmium, 5-8 g/t silver and many other valuable components. About 300,000 tons of such clinker have already been accumulated in dumps, and when the plant is fully loaded, an additional 70,000 tons of such valuable material is formed per year [7].

Tailing dumps and, especially, slag heaps are encroaching on suburban areas, occupying thousands of hectares of farmland, polluting the air basin and disfiguring the landscape. The assessment of damage from environmental pollution leads to a significant expansion of the boundaries of the economic feasibility of creating and using waste-free technology. Given this circumstance, the economic efficiency of combining production certainly increases and new criteria arise for the formation of production structures in industry related to environmental protection [8-12].

In this regard, the task of creating a rational and integrated technology for processing slag and intermediate products of copper production is very topical [13].

The classical pyrometallurgical scheme for the production of blister copper at most plants in the world, including the Almalyk Mining and Metallurgical Combine, includes [14]:

- melting of the charge on the matte in a reverberatory furnace;
- smelting the charge for matte in an oxygen flash smelting furnace or in another type of autogenous process;
- matte conversion.

With such a technological scheme, the products of production are:

- slags of reflective melting;
- slag from oxygen-torch melting;

- converter slags.

Slags from copper production contain from 0.45 to 3.5% Cu and are not dump. Oxygen-smelting furnace (OSF) and reflective smelting slags are stored until an economically viable technology for their processing is created. Converter slag, containing up to 3.5% copper, is a recycled product and, for the most part, is processed in a reverberatory furnace (RF). However, this process has no prospects. This is due to the inherent technological disadvantage of the reverberatory furnace, which consists in obtaining a large amount of off-gases with high humidity and low sulfur dioxide content. This provision excludes their economically acceptable use for the production of sulfuric acid or the extraction of sulfur into marketable products. In the future, it is planned to withdraw the reverberatory furnace from the number of melting units for the processing of sulfide raw materials and replace it with an autogenous process. This situation significantly exacerbates the problem of converter slag processing and requires the creation of other alternative technologies for the extraction of copper and other elements from them [15-18].

Significant dehydration is achieved with an active change in the composition, structure and properties of slags. This is the main object of theoretical research and practical research on the development of cost-effective and environmentally friendly methods for the complex processing of copper-containing slags.

In terms of solving this complex problem, we have developed the main concepts determined by the necessary requirements for the developed technology, namely:

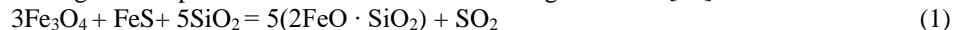
- the technology should be resource-saving and use only local non-deficient components as starting materials;
- the technology must ensure the absence of environmental pollution by smelting products beyond the permissible limits;
- technology should have prospects for further transition to low-waste;
- the implementation of the technology should be carried out on existing equipment with minimal costs for reconstruction [19].

Successful fulfillment of these requirements will allow Almayk MMC to become an enterprise with a complete metallurgical cycle, environmentally friendly in terms of metallurgical processing, achieve high technical and economic indicators and move on to the development of waste-free technology.

A theoretical study on the processing of copper slag and an analysis of the practical work of copper smelters made it possible to establish that the success of the depletion process is largely determined by the solution of the following problems:

- reduction of slag magnetite to FeO;
- adjusting the composition of the slag and work on the optimal content of such components as SiO<sub>2</sub>, CaO, Fe<sub>3</sub>O<sub>4</sub> and others;
- sulfiding of oxidized copper compounds and their transfer to the matte phase;
- bubbling the melt in order to create conditions for the coalescence of small matte drops;
- transfer of small drops of matte to the bottom phase by mixing with the extracting phase;
- the binding of sulfur into the condensed phase, which allows you to simultaneously reduce desulfurization to an acceptable limit and transfer it to matte.

During reflective melting, the reduction of magnetite is possible as a result of the following reactions [20]:



Which are intensified in the presence of quartz flux:



To solve the problem of copper slag depletion in the real conditions of the Almayk plant, the following materials can be used:

- solid carbon-containing reducing agents (coke, coal, clinker of the Almayk zinc plant);
- gaseous and liquid fuels;
- reducing agents containing non-ferrous metals with high affinity for oxygen (aluminum waste);
- gypsum from the neutralization of effluents from copper smelters;
- phosphogypsum - waste of the Almayk chemical plant.

Laboratory studies were carried out on the depletion of copper slags in series, including various man-made formations and semi-products of local industrial enterprises.

The selection of these materials was carried out taking into account the tasks we are solving for the reduction of magnetite, sulfiding of oxidized copper compounds, bubbling a liquid bath, creating a weakly reducing atmosphere in the furnace, and obtaining slag of optimal composition and properties. When selecting materials, we were guided by the main provisions of the depletion concept developed by us, which were considered earlier.

Of the numerous sources of raw materials, preference was given to those materials that included copper, noble metals and other elements. This makes it possible not only to solve the main problem of extracting copper from slag, but also to additionally obtain valuable metals.

The main object of research was the slags of the copper-smelting production of the Almayk Mining and Metallurgical Combine. Their compositions are shown in Table 1.

We subjected both stale accumulated and fresh formed slags to chemical analysis. Attention is drawn to the large scatter of slag compositions, especially in terms of copper content in them. In oxygen-torch smelting slags, the copper content ranges from 0.73 to 1.33%, in converter slags - 1.60 - 3.56%, the reflective limit - 0.29 - 0.72%. Such a wide range of slag compositions is explained by the specific conditions for conducting metallurgical melts and the nature of the incoming raw materials. The figures presented are

the average of several parallel analyzes and are therefore fairly reliable. For research work, we chose converter slags with the most common copper content in them in the range of 2.3 - 3.3%.

As the main reducing agent, we chose zinc clinker produced by the Almalyk Mining and Metallurgical Combine. This choice is due to both the content of valuable components in it and its high chemical activity. The composition of the clinker is presented in Table 2.

As a sulfidizing agent, we chose zinc tailings from the lead concentrating plant of the AMMC. The choice was due to its huge reserves, lack of demand, rather high content of sulfur and copper in them. Moreover, in terms of copper content, they are comparable to the copper-molybdenum ores of the Kalmakir deposit of the AMMC (0.37 - 0.42% Cu). The chemical composition of zinc tailings is presented in Table 3.

**Table 1.** Chemical composition of AMMC slag

№	Type slag	Content, %									
		Cu	Fe <sub>total</sub>	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	CdO	Zn	Pb	Fe <sub>3</sub> O <sub>4</sub>	S	MgO
1	2	3	4	5	6	7	8	9	10	11	12
1.	OFS	0,73	31,6	32,6	6,9	0,7	-	-	16,1	2,1	-
2.	OFS	0,74	37,6	31,9	5,6	0,6	0,5	2,1	-	0,38	-
3.	- « -	0,94	39,2	29,5	5,71	0,5	0,4	-	11,9	0,35	0,86
4.	- « -	0,94	55,2	32,8	2,9	4,3	-	-	-	1,23	2,5
5.	- « -	0,98	34,2	30,9	7,3	1,4	-	-	18,6	-	-
6.	- « -	1,20	39,1	26,9	6,3	2,1	-	-	19,7	-	-
7.	- « -	1,33	42,9	24,8	6,3	1,7	-	-	21,0	-	-
8.	CF	1,60	44,2	26,0	1,7	1,6	-	-	16,5	-	-
9.	- « -	1,95	46,8	23,2	2,1	2,2	-	-	23,2	-	-
10.	- « -	2,3	48,5	19,8	3,16	0,75	-	-	16,3	1,39	0,46
11.	- « -	2,4	45,3	20,2	1,6	1,7	-	-	27,3	1,3	0,4
12.	- « -	2,51	48,8	22,4	1,8	1,44	-	-	19,1	-	-
13.	- « -	3,05	48,7	21,2	3,1	0,56	-	-	22,0	-	0,56
14.	- « -	3,3	49,5	24,0	-	2,5	-	-	-	2,1	-
15.	- « -	3,56	46,56	19,0	3,26	1,57	-	0,52	-	2,0	-
16.	RF	0,29	41,7	30,6	2,4	3,6	-	-	-	0,6	1,6
17.	- « -	0,43	44,8	34,7	6,5	4,9	-	-	-	1,3	0,9
18.	- « -	0,46	49,1	35,6	3,2	1,8	-	-	-	0,4	3,6
19.	- « -	0,48	49,5	32,9	2,8	2,24	-	-	-	-	-
20.	- « -	0,52	44,6	36,4	6,3	3,1	-	-	-	2,1	0,7
21.	- « -	0,56	45,7	37,7	4,2	2,8	-	-	-	0,8	1,6
22.	- « -	0,61	4,6	31,0	3,8	4,6	-	-	-	1,2	2,4
23.	- « -	0,72	48,5	30,1	4,1	2,9	-	-	-	2,7	1,3

**Table 2.** Chemical composition of AMMC clinker

No.	Class clinker	Content, %										
		Cu	Zn	Pb	Fe	Cd	In	SiO <sub>2</sub>	As	Au	Ag	C
1	2	3	4	5	6	7	8	9	10	11	12	13
1	KL-2	2.24	2.35	0.5	30.06	0.01	0.001	15	0.3	5-8 g/t	300-500 g/t	12.0
2.	KL-3	2.21	2.69	0.6	34.0	0.01	0.009	18	0.3	2-5	250-300 g/t	12.5

**Table 3.** The chemical composition of the zinc tailings of the lead concentrator AMMC factories

No.	Element	Content, %	No. p.p.	Element	Content, %
1	2	3	4	5	6
1.	Pb	1,02	10.	Sb	0,0002
2.	Zn	1,65	11.	Te	0,0075
3.	Cu	0,30	12.	In	0,0003
4.	Fe	27,50	13.	Al <sub>2</sub> O <sub>3</sub>	4,25

5.	Cd	0,02	14.	Co	0,0075
6.	Bi	0,0033	15.	MgO	6,11
7.	S	21,4	16.	Se	0,0018
8.	SiO <sub>2</sub>	29,4	17.	Mn	0,5
9.	As	0,028	18.	CaO	7,61

When performing the work, most of the known, widely used, available methods and installations were used. Some techniques have been developed in the course of the present research.

### The main technological parameters of the depletion of copper-containing slags by reducing-sulfiding compositions

This article presents the results of depletion using reductive-sulfiding compositions (RSC) of the following compositions:

1. Converter clinker slag;
2. Converter slag-phosphogypsum ACS-limestone-CCP tailings;

In all experiments, if necessary, we changed the ratio of components in the system: slag-reducing agent-sulfidizer.

### Converter slag-clinker system

To study the effect of clinker consumption on the results of decalcification of converter slag, the first series of experiments was carried out with the addition of various amounts of reducing agent (clinker) to the initial melt.

Trial experiments have shown that the consumption of clinker in the amount of 10 - 30% reduces the copper content in the slag from 2.95 - 3.5 to 0.5 - 0.1%. At the same time, the content of magnetite in the slag decreases from 20 to 3.0 - 5.0%. Considering these results, as well as based on technical and economic calculations, in real research conditions, the addition of clinker to the initial converter slag amounted to 5–25%.

The results of laboratory heats are presented in table 4. and fig. 1 and fig. 2. With the addition of 10% to 25% clinker, three liquid phases were formed as a result of melting: slag, matte and metal alloy.

It was assumed that an increase in the amount of clinker should increase the degree of extraction of not only copper, but also iron from the slag. In this case, the composition of the slag should change in the direction of increasing the content of silicon dioxide. As can be seen from the results shown in Table 4, with the addition of 5% clinker, the iron content in the slag decreased by about 2% and then remained constant. The decrease in the silica concentration in the slag by almost 4% is also unusual. In addition, the copper content in the matte is unusually high (55–70%). The results obtained when melting slag together with clinker at 1573 K (1300 °C) may be due to the inefficient interaction of iron and carbon of clinker with slag due to poor contact and low reaction rate under these conditions.

It is important to find out this, because in industrial conditions of a reverberatory furnace, the clinker will directly melt together with the slag.

Slag melting was carried out with the addition of 20% clinker at various times of melt mixing with argon (from 10 to 40 minutes). The results of these heats are shown in tables 5. It is shown that in the case of intensive mixing, the reducing effect of clinker on slag increases significantly (Fig. 1), while the content of copper and zinc in the waste slag decreases to 0.33% and 0.02%, respectively. Melting products are only two phases: slag and sulfide-metal alloy containing 5-10% sulfur, 12-17% copper. As the mixing time increases, the content of copper and iron in the slag decreases from 1.6% to 0.6% and from 47% to 32%, respectively, and the silica concentration increases from 20% to 30%. The results obtained showed the fundamental possibility of the interaction of converter slag with clinker, but this process requires elevated temperatures (1300 °C). In addition, intensification can be achieved by mixing the melt and charge, introducing additional reagents.

Raising the temperature and intensive mixing in real conditions of a reverberatory furnace is difficult to implement. The most accessible is the introduction of additional reagents, which is taken as the basis for this work. From the results of melting slag with different amounts of clinker (Table 4), it can be seen that with an increase in clinker consumption, the slag yield decreases from 88% to 81%. This indicates that some of the oxides from the slag are reduced by clinker, and the degree of use of metallic iron and carbon for the dehydrogenation process is reduced. Kinetic difficulties lead to the fact that the metal sulfide alloy quickly enough passes into a liquid state and leaves the zone of interaction with slag and matte, forming a bottom phase. As a result, the sulfur present in the charge also passes into the matte.

**Table 4.** Results on the depletion of converter slags with AZP clinker (slag sample - 100 g) T - 1300 °C,  $\tau$  - 2 hours, Cu in slag - 2.3%

№	Charge %	matte output, %	Content in matte, %	slag output, %	Content in slag, %	Ext. Cu, %

			Cu	Fe	S	Zn		Cu	Fe	Cu	Fe	S	Zn	
1	2	3	4	5	6	7	1	2	3	4	5	6	7	1
1	5	1,7	66,3	7,1	17,2	0,4	1	5	1,7	66,3	7,1	17,2	0,4	1
2	5	1,67	70,7	4,8	18,1	-	2	5	1,67	70,7	4,8	18,1	-	2
3	5	1,6	71,2	5,3	18,9	-	3	5	1,6	71,2	5,3	18,9	-	3
4	10	1,5	71,6	4,5	18,2	-	4	10	1,5	71,6	4,5	18,2	-	4
5	10	1,43	72,8	5,7	17,3	0,6	5	10	1,43	72,8	5,7	17,3	0,6	5
6	10	1,54	72,1	4,4	19,3	0,5	6	10	1,54	72,1	4,4	19,3	0,5	6
7	10	1,1	68,5	7,3	18,5	-	7	10	1,1	68,5	7,3	18,5	-	7
8	10	0,9	64,8	5,4	20,1	-	8	10	0,9	64,8	5,4	20,1	-	8
9	15	0,7	58,5	10,1	21,2	0,8	9	15	0,7	58,5	10,1	21,2	0,8	9
10	15	0,5	63,1	9,8	19,1	-	10	15	0,5	63,1	9,8	19,1	-	10
11	15	0,5	61,2	11,7	21	-	11	15	0,5	61,2	11,7	21	-	11
12	20	0,89	61,5	11,3	18,8	0,9	12	20	0,89	61,5	11,3	18,8	0,9	12
13	20	0,4	58,2	12,6	18,3	1,06	13	20	0,4	58,2	12,6	18,3	1,06	13
14	20	0,7	57,9	10,4	17,7	-	14	20	0,7	57,9	10,4	17,7	-	14
15	25	0,61	56,6	13,7	19,7	-	15	25	0,61	56,6	13,7	19,7	-	15
16	25	0,8	56,5	14	16,5	1,0	16	25	0,8	56,5	14	16,5	1,0	16
17	25	0,73	54,8	14,5	18,5	-	17	25	0,73	54,8	14,5	18,5	-	17
18	25	0,70	55,2	13,9	17,4	0,8	18	25	0,70	55,2	13,9	17,4	0,8	18

Note. The yield of the metal phase ranges from 5 to 17%; Contains Fe -70 - 75%, Cu -7 - 15%, S -5 - 8%.

The intensification of the process of interaction of slag with matte can be achieved by joint mixing of these melts. To study these processes in relation to the real conditions of the AMMC, special studies were carried out. Argon was used as the mixing phase. The results of the experiments are presented in table 5.

Analysis of the results presented in Table 5 shows that the extraction of copper into matte increases with increasing mixing time from 69.8% to 77.5%. However, the residual copper content in the depleted slag remains rather high (0.57–1.02%). Despite the fact that the slag yield is low (10.0 - 10.7%), copper losses will still be significant and this mode is hardly advisable to recommend for industrial implementation.

Comparison of the data presented in tables 4 and 5 shows a significant reduction in the copper content in the matte. This can be explained by a decrease in the duration of the dehydration process, a reduction in the consumption of the reducing agent, and a change in the conditions for the implementation of the technological process.

**Table 5.** Results of experiments on the depletion of converter slags of RSC with stirring with argon. Settling time - 20 min. Cu in slag - 2.3%, T - 1300 °C. Charging clinker AZP-20% of the weight of the original slag.

N o.	Time, min.	Exit matte %	Content in matte, %			Extracti on to matte, %	slag outlet, %	Content in slag, %					
			Cu	Fe	S			Cu	Fe	SiO <sub>2</sub>	CaO	S	Zn
1	10	10	14,9	70,6	6,07	69,8	88,2	0,89	43,7	22	1,48	2,5	0,37
2	20	10,9	12,7	44,8	5,6	60,2	87,7	1,02	39,4	24,7	1,29	2,7	0,09
3	20	10,4	15,3	64,3	5,1	69,1	87,9	0,79	42,6	23,8	1,3	2,1	0,1
4	20	14,7	12,1	70,1	5,6	76,8	84,4	0,61	35,4	25,6	1,8	1,2	0,04
5	40	10,3	17,2	54,9	3,8	77,5	88,1	0,57	32,4	30,6	1,88	1,5	0,03

To implement the depletion process, it is advisable to study the effect of mixing with argon under the conditions of using not only clinker, but also other components of the reduction-sulfiding complexes.

The results of laboratory studies on the dehydrogenation of converter slags with the loading of Almayk zinc plant (AZP) clinker, gypsum from the neutralization of the sulfuric acid shop of the copper smelter with the addition of limestone and tailings of the copper concentrating plant under the conditions of stirring the melt with argon are presented in Table 6.

**Table 6.** Results of studies on the depletion of converter slags with the addition of RSC (20% clinker, 5% gypsum, 5% limestone by weight of the slag) under conditions of mixing with argon. Experimental conditions: slag sample - 30 g, settling time - 30 min; Cu in slag - 2.3%, T - 1300 °C.

N o.	Mixi ng time, min	Matt e yield, %	Content in matte, %			Retri eve in pieces, %	Slag yield, %	Content in slag, %								Des ulfur izati on	Retri eve copp er in matt e
			Cu	Fe	S			Cu	Fe	SiO <sub>2</sub>	CaO	S	Zn	Fe <sub>3</sub> O <sub>4</sub>			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	



1	10	12,4	18,6	44,9	22,3	86,8	86,2	0,51	37,6	27,8	4,6	0,7	0,5	7,4	4,1	86,8
2	10	12,0	18,0	46,8	23,1	83,2	85,8	0,66	41,3	26,5	4,0	0,6	0,2	6,3	7,6	83,2
3	20	11,6	20,5	43,6	22,8	87,5	84,2	0,33	43,2	30,8	5,7	0,3	0,07	2,8	13,2	87,5
4	30	12,1	19,2	46,3	23,5	90,0	82,3	0,37	40,2	32,6	4,3	0,4	0,02	2,1	16,9	90

The results of the experiments showed that under depletion under these conditions, a sufficiently high extraction of copper into matte is achieved. However, the matte is poor (18.0 - 20.5% Cu). The residual copper content in the depleted slag is quite low. So, under the conditions of experiments 3 - 4, the copper content in the slag is only 0.33 - 0.37%, which is quite close to the concentration in the waste products. The conditions of such experiments could be taken as a basis for further studies, however, stirring with argon in the real conditions of experiments 3 and 4, a sufficiently high desulfurization is observed, which can lead to the release of sulfur-containing gases into the air pool beyond the established norms.

### Interaction in the converter slag-clinker-limestone - FeS<sub>2</sub> (LCP tails) - SiO<sub>2</sub> (CCP tails)

The study of the effect of sulfidizing agents on the efficiency of depletion of converter slag with clinker was carried out by adding pyrite-containing tailings of a lead concentration plant (LCP) to the charge. At the same time, the composition of the slag was corrected by adding limestone and tailings of a copper concentrating plant (CCP) containing quartz. The tailings of lead concentrators contain 50-55% pyrite.

In this work, a cycle of depleted heats was carried out at a temperature of 1300 °C according to the method described above. The amount of reducing agent (clinker), sulfidizing agent (LCP tailings) and flux additives was changed. When calculating additives, we proceeded from the need to change the composition of both matte and slag in a wide range. The composition of sulfiding reducing complexes, the amount of fluxes and the results of the experiments are shown in Table 6 and Fig. 1 - 3. From the results obtained, first of all, consider the patterns of matte formation.

From the given data, it can be seen that the yield of matte is directly proportional to the amount of sulfidizing agent over the entire range of changes considered. It can be seen that the same amount of sulfidizer with an increase in the addition of clinker gives an increase in the yield of matte. This indicates that the formation of the matte is carried out mainly due to the pyrite of the LCP tailings and the metallic iron of the clinker. To clarify this dependence, the results of the interaction are presented in coordinates: the weight of the matte in grams - the amount of pyrite in grams with different additions of clinker (% of the weight of the slag). As can be seen in Fig. 1, the considered relationship for series of experiments with the same amount of clinker turned out to be linear. At the same time, it can be established that the addition of one gram of pyrite leads to an increase in the amount of matte at 5% clinker by 1.3 grams, and at 20% clinker by 1.2 grams. A comparison of the stoichiometric ratios between FeS<sub>2</sub> and Cu<sub>2</sub>S shows that excess pyrite sulfur in the amount 0,27 g per 1 g pyrite, in the case of copper sulfiding, gives an increase in the weight of the matte by 1 g, and in the case of iron sulfiding, by 0.45 grams. This gives grounds to believe that, mainly, the sulfidizing agent is spent on iron sulfiding. In addition, comparing the increase in matte weight by 2.6 and 2.4 grams (with the same amount of sulfidizing agent - 5.12 grams) and the increase in the addition of clinker from 10% to 20% (which corresponds to the introduction of 1.7 grams of metallic iron), it can be noted the following: with an increase in the amount of clinker, the weight of the matte increases not only due to the transition to matte, but also an increase in the extraction of copper, which may be associated with a decrease in desulfurization.

If we take into account the fact that all depletion melts were carried out under reducing conditions and the magnetite content in the slag was in the range of 2-5%, it is possible to approximately calculate (by the content of sulfur, copper and iron) the degree of matte metallization, neglecting the oxygen content in it. In a comparative analysis of relative values, this error will play an even smaller value.

Useful information for predicting the composition of the matte during depletion melting with pyrite-containing WSC is provided by the dependence of the copper content in the matte on the amount of sulfidizing agent introduced in graphical form. The results confirm the significance of both the amount of the sulfidizing agent and the reducing agent in the formation of the matte composition and make it possible to predict the quality of the resulting extractive phase with high accuracy.

As noted earlier, one of the objectives of the developed technology for the depletion of RSC converter slags in a reverberatory furnace is to minimize desulfurization in order to reduce the emission of sulfur with exhaust gases into the atmosphere. It is known that desulfurization is to some extent determined by the degree of metallization in the slag-matte system. The degree of desulfurization during melting, depending on the amount of clinker in the RSC.

The results obtained confirm the inversely proportional relationship between desulfurization (less than 5%) and the introduction of clinker at least 20% of the weight of the processed slag. The constructed dependence shows that the data obtained are located in a fairly wide band, determined by the amount of sulfidizing agent introduced together with clinker. Thus, when the amount of sulfidizer is more than 20% by weight of the slag, desulfurization of less than 5% requires more than 20% of the clinker.

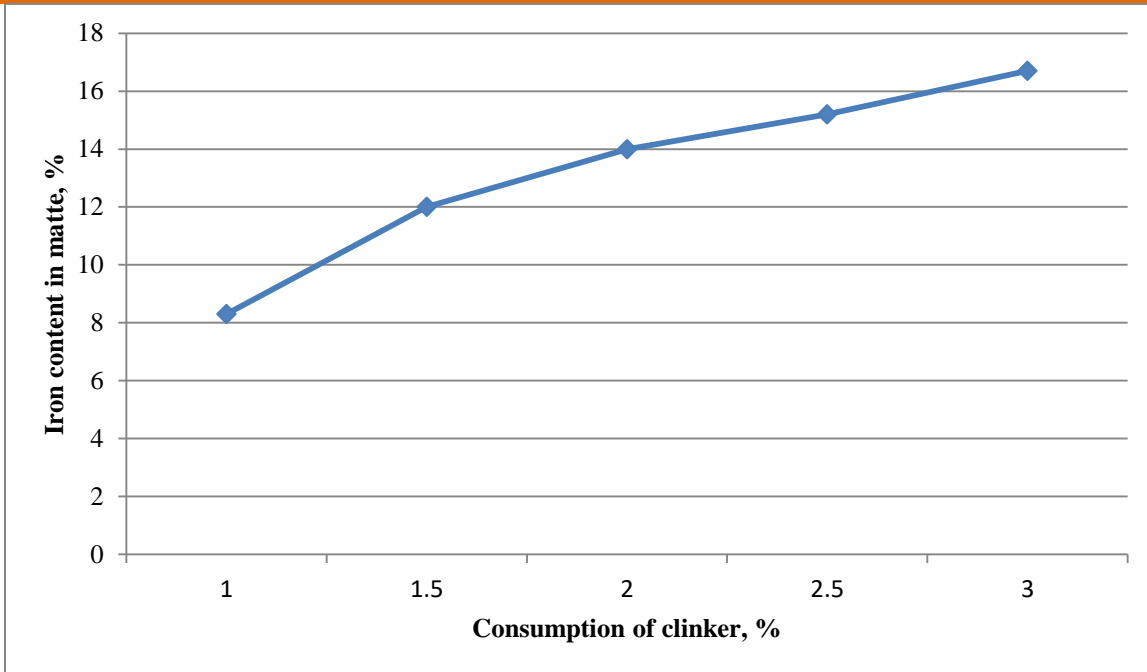


Fig.1. Dependence of  $Fe_{met}$  content in matte on the ratio of reducing agent (clinker): sulfidizer (LCP tailings).

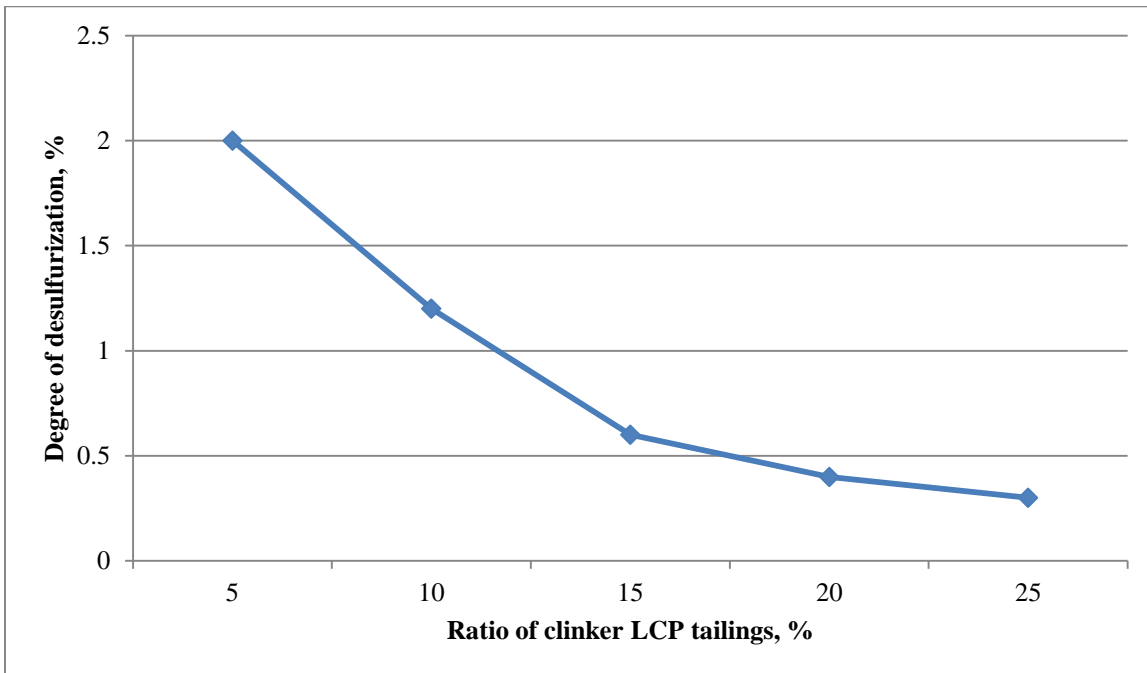
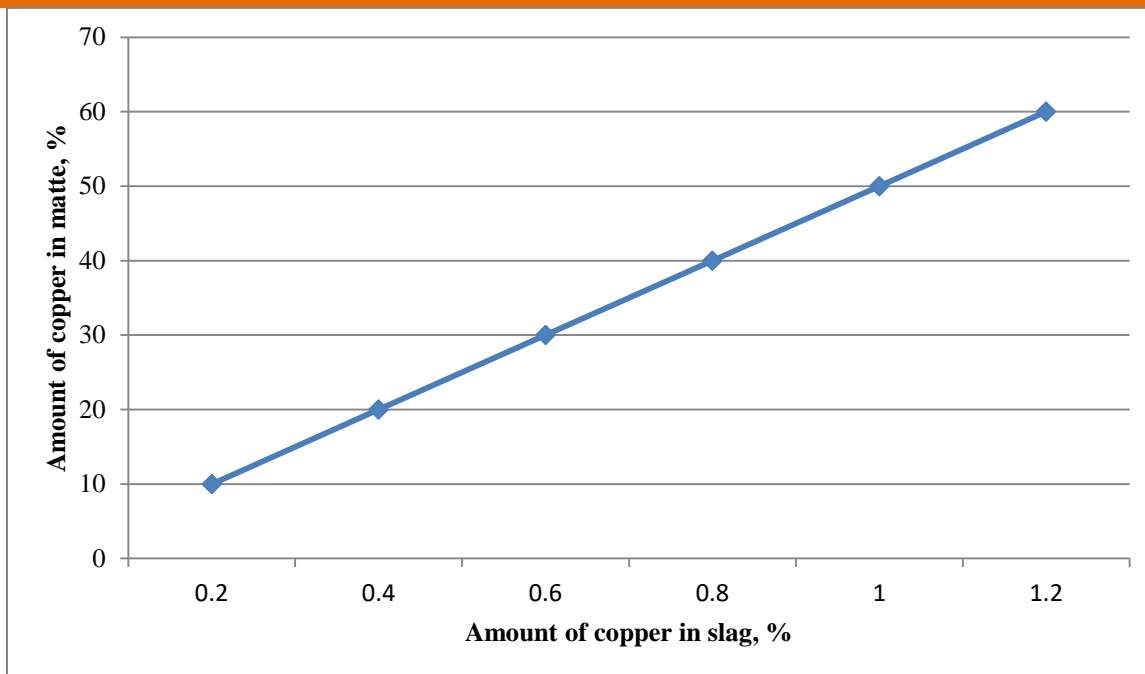


Fig.2. Dependence of the degree of desulfurization on the ratio of clinker: LCP tailings.



**Fig.3.** Dependence of the copper content in waste slag on the copper content in the matte

The successful solution of an important problem - the extraction of copper from converter slag by processing them with RSC - is associated with a number of factors. From the theory and practice of depletion, it is known that the most important of them are the content of copper in the matte and the optimal composition of the slag in terms of  $\text{SiO}_2$  and  $\text{CaO}$ .

The results obtained on the residual content of copper in depleted slags, depending on the factors noted above, are presented in Fig. 1-3. In all cases, there are significant dispersions in the presented interdependencies. There is a general explanation for this. It lies in the fact that, firstly, in the slag, in addition to the dissolved ones, there are also mechanical losses, which can be different, and secondly, in addition to the copper content in the matte, the losses can also be affected by a different degree of metallization in the system, which corresponds to a different partial pressure, and, consequently, to the activity of oxygen. But, despite the significant dispersion, the presented interdependencies clearly indicate that both a decrease in the copper content in the matte and an increase in the content of  $\text{SiO}_2$  and  $\text{CaO}$  in the slag to 35% and 6%, respectively, contribute to a more complete separation of copper from slags.

## CONCLUSIONS

1. According to the developed methodology, systematic studies were carried out on the depletion of converter slags with RSC in the following compositions:

- converter slag – clinker;
- converter slag - clinker - limestone -  $\text{FeS}_2$  (LCP tailings) -  $\text{SiO}_2$  (CCP tailings).

2. Based on the results of the experiments, the technological and environmental characteristics of RSC of various compositions were compared and recommendations were developed for their use in industrial testing.

3. Optimal ratios of RSC components have been determined, using which the most satisfactory results are obtained.

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