

Electrosmelting of Lead-Containing Dusts from Copper Smelters

G. Z. Moldabayeva¹ · S. K. Akilbekova¹ · K. K. Mamyrbayeva¹ · B. Mishra²

Published online: 28 August 2015

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Abstract Experimental and mathematical modeling work has been conducted to develop an effective technological scheme for processing lead-containing dusts generated in copper smelting. The work incorporates conditions of melting, charge composition, and the physical parameters of the dust. The optimal conditions of electrosmelting have been established for complete and comprehensive extraction of the basic and rare metals from the dust. In this one-stage processing, three intermediate products have been recovered: crude lead; basic matte-slag melt containing Cu, Zn, and As; and secondary sublimates enriched in Cd and Re.

Keywords Lead-containing dust · Copper smelting · Electro-thermal processing · Rough lead · Basic matte-slag melt · Rhenium · Secondary sublimates · Mathematical modeling

Introduction

A significant number of diverse compositions of dry dusts and sublimates are obtained during the roasting, sintering, sulfide smelting, converting of copper and copper-lead mattes from copper production plants. For example, dusts of copper-smelters contain valuable metals, such as Pb, Zn, Cu, Cd, Bi, Sb, Re, Te, Se, and Tl. Due to the low content of these metals, they are essentially considered secondary concentrates. Concentrations of these and other rare dispersed elements are 4–10 times higher than in the initial mined raw materials [1].

Since accumulation of dusts in these processes is an unavoidable problem and is generally considered metallurgical waste, development of new technological methods for their complex processing is required to achieve complete extraction of base metals and rare metals. Specificity of physico-chemical properties and relatively high content of valuable components in dusts of copper smelters formed the basis for development of technological schemes of separate processing of these dusts to recover lead, zinc, cadmium, rare dispersed metals, and output of arsenic from the production.

Until now, metallurgical plants dusts have been recycled by various schemes and they usually had low extraction of basic (Pb, Cu, and Zn) and associated metals (Se, Te, In, Cd, Tl, and Re). In most cases, dusts processing is carried out by hydrometallurgical method. As the leaching reagents, solutions of acids, alkalis, and sodium salts [2–4] were investigated. There are known experimental data on the two-stage leaching of the copper smelting productions dusts by sulfuric acid solutions, aqueous solutions of sodium carbonate and nitric acid, as well as with the presence of oxidizing agents [5–8].

The contributing editor for this article was K. Yamaguchi.

✉ B. Mishra
bmishra@mines.edu

G. Z. Moldabayeva
g.moldabaeva@bk.ru

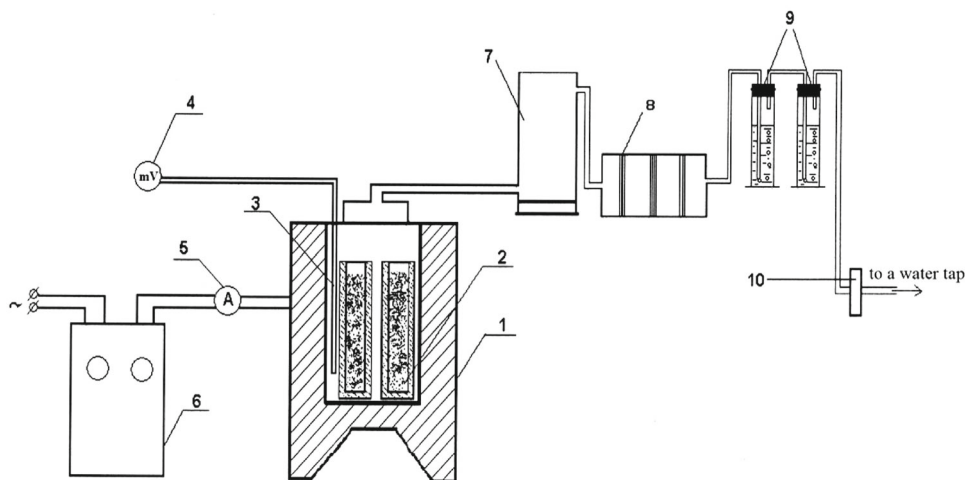
S. K. Akilbekova
sh_akybekova@mail.ru

K. K. Mamyrbayeva
gulzira70@mail.ru

¹ Kazakh National Technical University Named After K.I. Satpayev, Almaty, Kazakhstan

² Colorado School of Mines, Golden, CO, USA

Fig. 1 Experimental apparatus for electric smelting of lead-containing dust



1 - shaft electric furnace; 2 - the crucible with the charge; 3 - thermocouple; 4 - millivoltmeter; 5 - ammeter; 6 - voltage regulator; 7 - dust chamber; 8 - bag filters; 9 - column for the analysis of gases and additional dust collection; 10 - water jet pump

Along with the hydrometallurgical methods of dusts processing, the pyrometallurgical processes are also considered. There is information in the literature on processing of lead-bearing dusts by roasting of specially prepared charge, a heat treatment in one or several stages and the reduction smelting in a wide range of temperatures with additives of various reagents [9–13].

Overview of the various methods of lead-bearing dusts processing of copper smelters indicates that, despite the wide range of used technology, they do not always solve the problem of complex extraction of all valuable components from this type of raw material. Most of the considered methods are characterized by a high consumption of expensive reagents, circulation of a large number of ballast returns (in the form of sulfate lead cakes), and low extraction of rare and dispersed elements. Therefore, it is necessary to find out optimal ways of complex processing of lead-containing dusts using the electrothermal combined method, which is the most promising and environmentally feasible technology [14].

Experimental Methods

As the starting materials for experiments on electrothermal recycling of lead-containing dust of copper smelters, sodium sulfate, sodium carbonate (technical soda containing 96.5–97 % Na_2CO_3); as a reducing agent, charcoal and coke fines were used.

The process equipment (Fig. 1) consisting of a shaft furnace, dust collection devices, and the absorption columns for the analysis of exhausted gases was used with a semi-automatic adjustment of electrothermal melting modes with controlled electrical load and temperature. This equipment allowed the study of lead-containing dusts’ electrothermal processing modes and to justify technology parameters, such as charge composition, melting temperature, and exposure duration. Weighing of starting materials was performed on electronic scales (MW-1200 with an accuracy of ± 0.0001 g). Weighed masses of lead dusts were mixed with sodium sulfate, soda and reducing agent in different ratios according to

Table 1 Levels of investigated experimental variables

Experimental variables	Level				
	(i)	(ii)	(iii)	(iv)	(v)
x_1 , the temperature, °C	850	950	1050	1150	1250
x_2 , the exposure time, min.	12	24	36	48	60
x_3 , the addition of Na_2CO_3 , % of dust content	10	20	30	40	50
x_4 the addition of Na_2SO_4 , % of dust content	2	4	6	8	10
x_5 , the addition of C, % of dust content	4	8	12	16	20

the goals of the study. Further, carefully intermixed charge was placed in alumina crucibles, which were put into an electric furnace [1] (Ref. Fig. 1 for identifying the equipment parts description numbers) after which the furnace temperature was raised to the required level. Control and measurement of the temperature in the reaction zone of the shaft electric furnace was performed by tungsten-rhenium thermocouple [3] and recorded with a millivoltmeter [4]. Upon reaching the desired temperature in the reaction zone, the initial charge exposure was carried out under the given time profile of 12–60 min. After completion of the experiment, crucibles were removed from the furnace, weighed, and cooled products were subjected to chemical and mineralogical analyses. During the smelting, generated sublimes were trapped in a dust chamber [7] and the filter bags [8].

Metallurgical processing of complex materials, such as dusts of copper smelters, is not only influenced by the charge composition, but also by the physical and chemical parameters of the process. In this case, identification of parameters of technological process requires complicated

multifactorial analysis. Staging of experiments, considering all factors would require an infinitely large number of tests. To solve this difficult problem of optimizing the number of tests, the method of mathematical modeling was employed which reduced the necessary amount of experiments for several tested parameters.

To study the processes in specific conditions, the methodology of mathematical modeling proposed by Malyshev, based on the equation of Protodjikonov [15, 16], was used. Determination of the conditions for more complete and comprehensive extraction of heavy non-ferrous (Pb, Cu), small (Cd), and rare (Re) metals into the corresponding intermediates in electrosmelting of copper smelters dusts were determined according to the five-factor experimental plan. The dependence of the extraction degree from dust was studied for lead into crude lead, copper—into matte-slag melt, cadmium and rhenium—into sublimes on the experimental variables of temperature and exposure time and material variables of soda, sulfate solution, and coke additions as wt.% of lead dust content. In accordance with the modeling matrix for the five factors, 25 independent experiments were conducted on five levels of each factor (Table 1).

Soda smelting reduction, i.e., smelting with the addition of sodium carbonate and coal/coke, provides crude metal recovery of the main component from the dust, lead, in the first stage of pyrometallurgical process. Next, black lead goes through standard refining process. The role of sodium sulfate is to melt the products and make them fusible, enabling easy black lead separation from the matte-slag melt.

The amounts of sodium sulfate, soda and coke, are added to the melt in an amount greater than the stoichiometric requirement to produce lead bullion and copper matte in the slag product, cadmium, rhenium sublimes for copper, cadmium and rhenium in sulfide form, and lead in the form of crude metal.

Analysis of the thermodynamic parameters of complex reactions, which occur during the melting of lead dust with sodium sulfate and sodium carbonate in the presence of carbon in the temperature range studied, showed that lead reduced to the metal and cadmium transferred to the sublimes. As the temperature increases, the probability of transition of lead metal and cadmium into sublimes increases. Rhenium sublimes beneficially into a heptavalent rhenium oxide and copper goes into sodium matte-slag melt. It has been established that conversion to metallic lead is the most probable thermodynamic reaction when lead sulfate and oxy-sulfate react with sodium sulfate, sodium carbonate, and carbon. Gibbs free energy has a negative value even at 573 K. With increasing temperature, the thermodynamic probability of the studied reactions also increases.

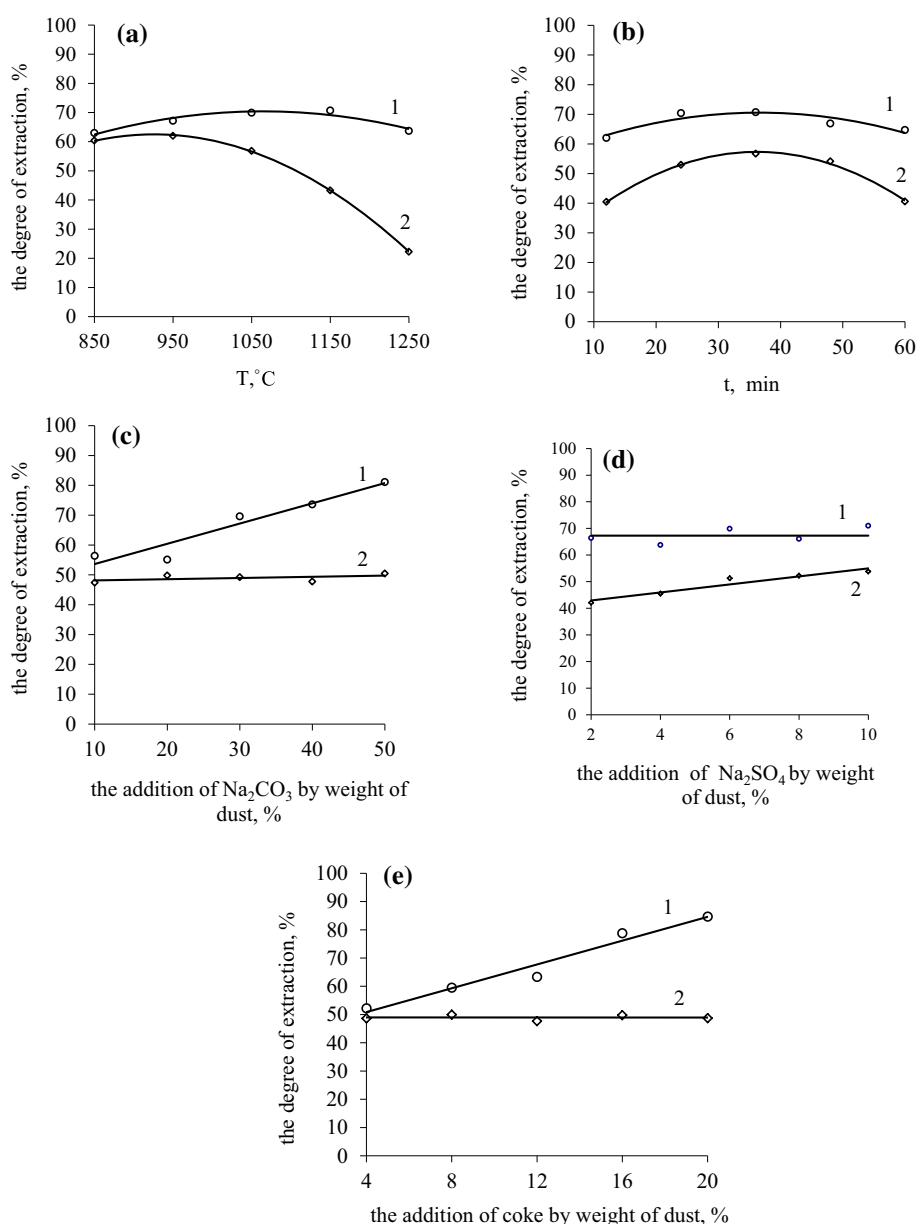
Table 2 Plan-matrix of five-factor experiment

Test no.	Levels of factors				
	x_1	x_2	x_3	x_4	x_5
1	850	12	10	2	4
2	850	36	30	6	12
3	850	24	20	4	8
4	850	60	50	10	20
5	850	48	40	8	16
6	1050	12	30	4	20
7	1050	36	20	10	16
8	1050	24	50	8	4
9	1050	60	40	2	12
10	1050	48	10	6	8
11	950	12	20	8	12
12	950	36	50	2	8
13	950	24	40	6	20
14	950	60	10	4	16
15	950	48	30	10	4
16	1250	12	50	6	16
17	1250	36	40	4	4
18	1250	24	10	10	12
19	1250	60	30	8	8
20	1250	48	20	2	20
21	1150	12	40	10	8
22	1150	36	10	8	20
23	1150	24	30	2	16
24	1150	60	20	6	4
25	1150	48	50	4	12

Table 3 Results of the copper smelter dusts' electrosmelting with the use of mathematical modeling parameters

Test no.	Levels of factors			Extraction of Pb to rough lead (%)			Extraction of Cu to the melt (%)			Extraction of Cd to sublimates (%)			Extraction of Re to sublimates (%)			
	T , °C	t , min	Consumption, % Na ₂ CO ₃ Na ₂ SO ₄ C	Y_{exp}	Y_{calc}	Note	Y_{exp}	Y_{calc}	Note	Y_{exp}	Y_{calc}	Note	Y_{exp}	Y_{calc}	Note	
1	850	12	10 2	4	39.88	33.53	Equations error, abs. %: $\sigma = 11.4$	43.80	39.79	Equations error, abs. %: $\sigma = 7.31$	55.83	63.99	Equations error, abs. %: $\sigma = 11.2$	33.22	42.25	Equations error, abs. %: $\sigma = 12.0$
2	850	36	30 6	12	63.19	64.67	A correlation coefficient at $N = 25$ and $K = 5$: $R = 0.77$	69.72	65.25	A correlation coefficient at $N = 25$ and $K = 5$: $R = 0.91$	61.39	69.20	A correlation coefficient at $N = 25$ and $K = 5$: $R = 0.87$	59.61	64.52	A correlation coefficient at $N = 25$ and $K = 5$: $R = 0.84$
3	850	24	20 4	8	30.98	48.98	$t_R = 8.24 > 2$	63.13	56.57	$t_R = 23.07 > 2$	77.45	78.97	$t_R = 15.6 > 2$	36.61	52.83	$t_R = 12.44 > 2$
4	850	60	50 10	20	94.13	86.71		57.50	50.97		12.20	11.05		97.61	91.27	
5	850	48	40 8	16	86.74	78.26		67.80	64.00		50.55	40.59		98.12	77.33	
6	1050	12	30 4	20	91.16	81.51		44.23	42.59		85.08	92.96		97.28	88.88	
7	1050	36	20 10	16	69.13	74.17		71.80	73.29		53.77	36.09		81.64	73.57	
8	1050	24	50 8	4	75.06	65.59		65.58	64.00		46.77	35.69		77.00	80.03	
9	1050	60	40 2	12	64.13	72.31		39.50	39.79		90.40	80.95		99.09	85.79	
10	1050	48	10 6	8	50.29	49.22		63.16	60.28		73.86	84.58		55.46	55.04	
11	950	12	20 8	12	54.36	56.34		55.70	53.05		72.05	55.37		44.56	62.77	
12	950	36	50 2	8	79.79	76.33		64.81	63.00		69.10	56.08		87.08	80.17	
13	950	24	40 6	20	96.73	96.29		67.50	66.38		65.55	70.20		98.12	90.89	
14	950	60	10 4	16	67.67	55.65		49.70	46.90		63.39	77.80		65.70	58.95	
15	950	48	30 10	4	54.81	52.21		72.30	74.57		35.74	30.73		45.89	59.94	
16	1250	12	50 6	16	88.80	78.06		18.70	8.62		29.68	35.79		91.18	93.34	
17	1250	36	40 4	4	41.18	53.82		24.40	11.64		87.22	78.86		78.80	84.47	
18	1250	24	10 10	12	67.42	49.15		27.60	12.87		45.35	26.15		98.53	94.31	
19	1250	60	30 8	8	57.34	49.93		19.10	9.16		54.96	50.04		91.22	82.74	
20	1250	48	20 2	20	72.70	69.90		21.46	10.05		94.23	97.53		93.50	91.64	
21	1150	12	40 10	8	79.36	61.32		39.75	35.49		22.38	23.82		86.70	85.67	
22	1150	36	10 8	20	56.77	70.09		52.95	48.23		67.82	63.50		49.21	74.34	
23	1150	24	30 2	16	81.71	78.20		40.83	36.80		96.39	99.40		98.81	89.73	
24	1150	60	20 6	4	50.13	42.30		37.12	31.59		92.54	80.67		84.35	82.57	
25	1150	48	50 4	12	67.77	84.62		45.87	39.39		63.93	55.04		89.37	82.22	

Fig. 2 Particular dependences of the extraction degrees of lead into the rough lead (1) and copper into a melt (2) on various factors



At low temperatures, formation of CdO is most probable thermodynamically, and the conversion to the metal cadmium as the reaction product of cadmium sulfate with soda and cadmium oxide with sodium sulfate and carbon occur.

For the formation reactions of thiosalts, copper has negative values of Gibbs energy at temperatures below 773 K, which indicates the possibility of forming more thiosalts of Cu in solid phases. The thermodynamically most probable formation reaction of copper thiosalt is $\text{Na}_2\text{Cu}_8\text{S}_5$. All studied processes of the oxidation of rhenium compounds have negative values of Gibbs energy. Thermodynamically it is most likely the formation of heptavalent rhenium oxide, Re_2O_7 , occurs from its sulfide.

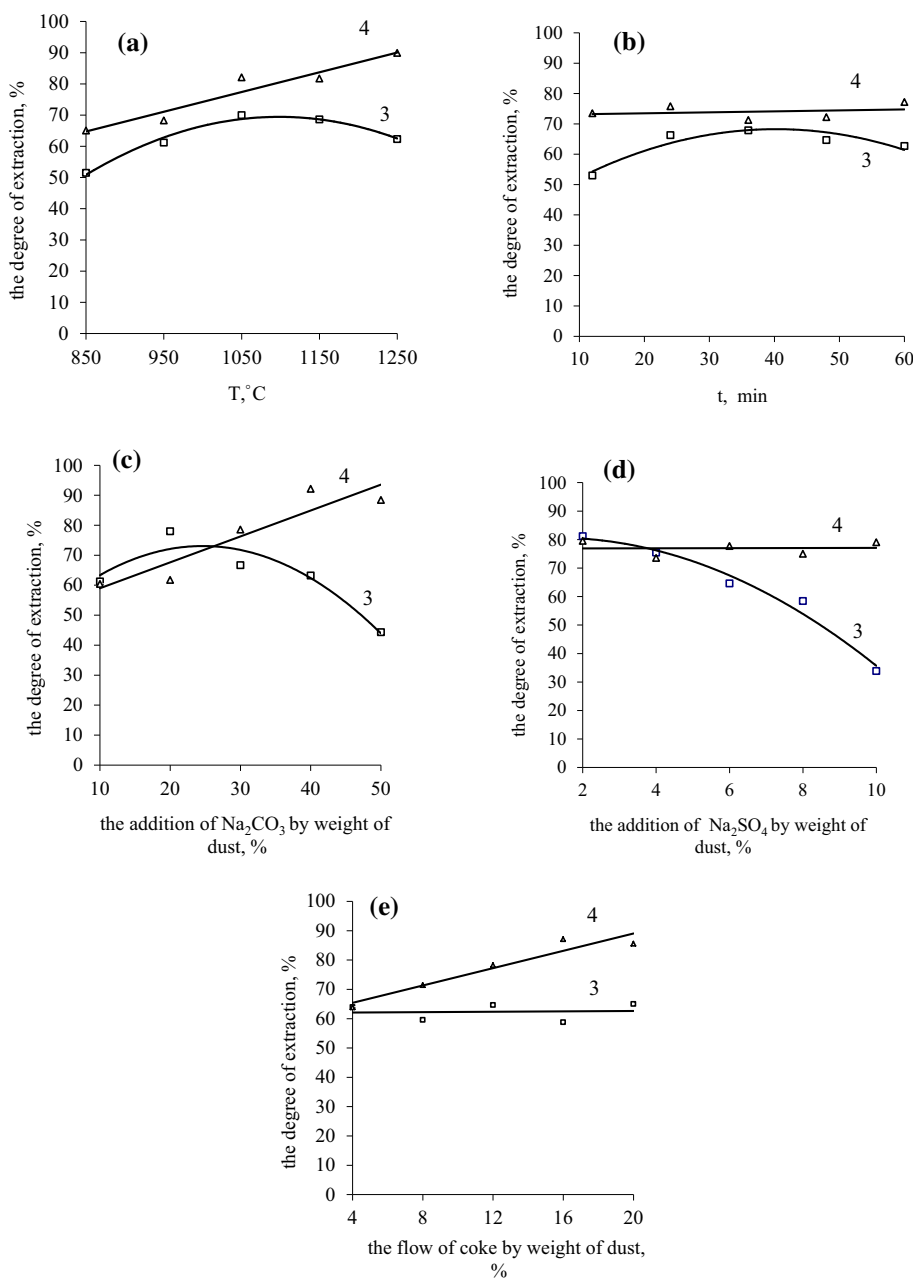
Under laboratory conditions, the initial crucible is cooled and slag, matte-product, and lead bullion are

separated by density and color. Sublimates are trapped in cyclones.

Sodium matte-slag melt is subjected to hydrometallurgical processing, followed by sulfation into cakes, as shown in Fig. 4. Aqueous leaching conditions are a temperature of 90 °C for 120 min with a stirring rate of 500 rpm. Extraction of heavy non-ferrous metals (Pb, Zn, and Cu) into cake was 97.1–99.8 %, and sodium and arsenic almost completely transferred to the leach solution.

Processing of the residue cake from the aqueous leach comprised matte-slag melt with sulfuric acid at a temperature of 350 °C, followed by aqueous leaching recovery of two products: lead sulfate was extended to smelting process and zinc sulfate solution rich in copper was in turn fed to electrowinning of these metals.

Fig. 3 Particular dependences of the extraction degree of cadmium (3) and rhenium (4) into the sublimes from the investigated factors



The structure of experiment plan was such that during all tests each level of any factor met once with each level of all other factors, thereby providing averaging of influence of any factor in sampling of the experimental results at any level. Experimental conditions are shown in Table 2. The parameters have to be selected based on the phase rule. The parameters are chosen as basic parameters for commodity products. Many studies conducted use not even five, but only four factorial experiments with 25 experiments. This is due to the fact that conducting 25 experiments was found

to be sufficient to determine the controlling factors that affect the final results.

Results and Discussion

Based on the experimental values obtained (Table 3), graphs were plotted (Figs. 2, 3) showing particular dependency of the degree of metals extraction using the studied factors, which were approximated by the corresponding equations

Table 4 Partial dependencies equation, correlation coefficient, and their significance factor

Private dependence of the extraction degree	Correlation coefficient, R	Correlation coefficient significance, t_R
Pb in black lead		
$y_1 = 69.95 - 0.00022 \cdot (x_1 - 1050)^2$	0.70	2.382
$y_2 = 70.71 - 0.0145 \cdot (x_2 - 36)^2$	0.85	5.302
$y_3 = 44.79 + 0.72 \cdot x_3$	0.89	7.412
$y_4 = 61.15 + 0.974 \cdot x_4$	0.43	0.902
$y_5 = 42.41 + 2.11 \cdot x_5$	0.97	28.432
Cu in matte-slag melt		
$y_1 = 62 - 0.00057 \cdot (x_1 - 950)^2$	0.89	7.402
$y_2 = 56.74 - 0.03 \cdot (x_2 - 36)^2$	0.98	42.862
$y_3 = 47.75 + 0.0405 \cdot x_3$	≈ 0	≈ 0.2
$y_4 = 39.91 + 1.509 \cdot x_4$	0.95	16.882
$y_5 = 48.97 - 0.001 \cdot x_5$	≈ 0	≈ 0.2
Cd in sublimates		
$y_1 = 70.5 - 0.00038 \cdot (x_1 - 1080)^2$	0.94	13.992
$y_2 = 67.86 - 0.0197 \cdot (x_2 - 36)^2$	0.68	2.202
$y_3 = 77.0 - 0.0519 \cdot (x_3 - 23)^2$	0.83	4.622
$y_4 = 81.19 - 0.887 \cdot (x_4 - 2)^2$	0.90	8.202
$y_5 = 65.0 - 0.156 \cdot (x_5 - 12)^2$	≈ 0	≈ 0.2
Re in sublimates		
$y_1 = 11.252 + 0.063 \cdot x_1$	0.95	16.882
$y_2 = 69.39 + 0.203 \cdot x_2$	0.096	0.172
$y_3 = 50.36 + 0.864 \cdot x_3$	0.90	8.202
$y_4 = 75.94 + 0.175 \cdot x_4$	≈ 0	≈ 0.2
$y_5 = 59.47 + 1.48 \cdot x_5$	0.94	13.992

with high correlation coefficients ($t_R > 2$). Based on the significant partial dependencies, multifactorial generalized

equations for extracting degree of lead (A), copper (B), cadmium (C), and rhenium (D) were made:

$$y = \frac{[69.95 - 0.00022 \cdot (x_1 - 1050)^2] \times [70.71 - 0.0145 \cdot (x_2 - 36)^2] \times [44.79 + 0.72 \cdot x_3] \times [42.41 + 2.11 \cdot x_5]}{(66.99)^3} \quad (1)$$

$$y = \frac{[62 - 0.00057(x_1 - 950)^2] \times [56.74 - 0.03(x_2 - 36)^2] \times [39.91 + 1.509 \cdot x_4]}{(48.96)^2} \quad (2)$$

$$y = \frac{[70.5 - 0.00038 \cdot (x_1 - 1080)^2] \times [67.86 - 0.0197 \cdot (x_2 - 36)^2] \times [77.0 - 0.0519 \cdot (x_3 - 23)^2] \times [81.19 - 0.887 \cdot (x_4 - 2)^2]}{(62.705)^3} \quad (3)$$

$$y = \frac{[11.252 + 0.063 \cdot x_1] \times [50.36 + 0.864 \cdot x_3] \times [59.47 + 0.48 \cdot x_5]}{(76.92)^2} \tag{4}$$

Equations error was calculated by formula (4).

$$\sigma = \sqrt{\frac{\sum_1^n (y_{\text{exp}} - y_{\text{calc}})^2}{N - K - 1}}$$

where

N—number of described points;

K—number of acting factors;

y_{exp}—experimental result;

y_{calc}—theoretical (calculated) result.

The obtained results showed the coincidence of calculated and experimental values of the Pb, Cu, Cd, and Re extraction degrees to the corresponding intermediates (Table 3). Despite the fact that some results of experiment and calculation differ quite significantly, none of the experimental value deviates from the calculated amount by greater than 3σ. High correlation coefficients indicate, in turn, the adequacy of generalized Eqs. 1–4 (Table 3).

Thus, studies on the combined electrothermal processing technology of copper smelter dusts with addition of soda,

$$R = \sqrt{\frac{(N - 1) \sum_1^N (Y_e - Y_t)^2}{(N - K - 1) \sum_1^N (Y_e - Y_{\text{av}})^2}}$$

where, *N* is the number of points described, *K* is the number of operational factors, *Y_e* is the experimental result, *Y_t* is the theoretical result, and *Y_{av}* is the average experimental value. As it can be seen from Table 4, from all partial dependencies, only the 4th was insignificant, and it is excluded from further consideration.

Next, based on the significant private dependencies, multivariate generalized equation is compiled by following formula:

$$Y_g = \frac{\prod_{i=1}^n Y_i}{Y_{\text{av}}^{n-1}}$$

where, *Y_g* is the generalized function, *Y_i* is the dependent function. $\prod_{i=1}^n$ is the multiplication of all dependent functions and *Y_{av}* is the overall average of all values considered to the extent of the distribution per unit at the amount of private functions. Thus, the degree of extraction of lead (1) is obtained by:

$$y = \frac{[69.95 - 0.00022 \cdot (x_1 - 1050)] \times [70.71 - 0.0145 \cdot (x_2 - 36)^2] \times [44.79 + 0.72 \cdot x_3] \times [42.41 + 2.11 \cdot x_5]}{(6699)^3}$$

sodium sulfate, and the coke to the charge, in accordance with the modeling matrix for the five factors allowed multiple correlation equations for Pb, Cu, Cd, and Re extraction to respective products.

Initially, the curves are constructed according to the experimental values of dependent functions shown in Table 3. Next, to describe the data in Figs. 2, 3, corresponding empirical formulas are selected. For example, in lead, parabolic equation was used in the description of the partial dependencies of *y₁* and *y₂*, while for the description of partial dependencies *y₃*, *y₄*, and *y₅*, straight line equations were used (Table 4).

Next, using a non-linear multiple correlation coefficient, significance or insignificance of the functions is determined by the following formula:

Similarly, Eqs. 2, 3, and 4 are compiled.

Melting products obtained after experiment were examined by chemical analysis method. Table 5 shows the chemical composition of black lead and sodium matte-slag melt, which were obtained after fusion. X-ray diffraction was used in, addition, only to confirm the data of chemical analysis.

The optimum extraction conditions for lead to rough lead (up to 97 %), copper to the matte-slag melt (up to 70 %), cadmium (up to 95 %), and rhenium (up to 92.2 %) into the sublimates were found. These are temperature in the range of 1100–1175 °C; the duration of exposure in the range of 30–40 min; content of soda in the charge at 30–40 % and sodium sulfate at 6–8 % with coke requirement in the range of 10–12 % by weight of dust.

Table 5 Results of expanded laboratory studies of lead-containing dusts processing

Test no.	Uploaded by weight of dust (%)		Obtained (g)	The content of metals, wt. %				Extraction (%)											
	Na ₂ CO ₃	Na ₂ SO ₄		C	In rough lead		In thio-salts melt		To rough lead		To thio-salts melt		To sublimate						
				Pb	Cu	Pb	Cu	Cd	Re	Pb	Cu	Pb	Cu	Cd	Re				
A lead-containing converter dust. Chem. composition, weight %: Pb—39.01; Cd—1.29; Cu—4.29; Re—0.012																			
Terms weighed dust 1000 g, <i>t</i> = 1175°C, duration of exposure—30 min																			
(a)	40	8	10	379.6	636.6	98.8	2.16	2.38	5.36	0.21	0.0029	96.1	19.11	3.88	79.54	10.36	15.38	89.64	81.14
A lead-containing converter dust. Chem. composition, weight %: Pb—42.93; Cu—3.43; Zn—6.2 %; As—0; Cd—1.14; Re—0.0162																			
Terms weighed dust 500 g, <i>t</i> = 1175°C, duration of exposure—30 min																			
(b)	40	8	10	205.8	202.5	99.25	1.93	4.38	5.96	0.21	0.0031	95.2	23.16	4.13	70.37	7.46	7.75	92.5	89.0
(c)	40	8	10	212.0	203.6	98.43	1.17	2.87	6.81	0.25	0.003	97.2	14.46	2.70	80.85	8.90	7.50	91.1	89.1

After finding the optimal conditions for processing converter dusts, the scaled-up laboratory investigations were conducted. Experimental conditions and results are shown in Table 4. The table shows that the electrosmelting of lead-containing dusts under reducing medium using optimal conditions from bench-scale causes lead to go into the rough metal up to 97.7 %, and copper transition into matte-slag melt at 85.2 %. Extraction of cadmium and rhenium to sublimate was 98.1 and 89.8 %, respectively. Thus, an improvement was achieved for all four metals under the scaled-up condition giving higher confidence for the development of an industry-level process.

Extraction indices for Pb, Cu, Cd, and Re into the corresponding intermediates under laboratory conditions using a five-factor matrix modeling and scaled-up laboratory studies were mostly identical or better. A flow-sheet has been developed, as shown in Fig. 4, for the developed process. Conducted X-ray analysis (Fig. 5) showed that the values of interplanar spacings of obtained rough lead practically coincide with the tabulated data for the pure lead. Subsequently, rough lead goes to refining by standard techniques. Basic matte-slag melt and secondary sublimate are then processed by hydrometallurgical methods for the recovery of Cu, Cd, and Re.

Benefits of electrothermal processing of lead-containing dusts include practically complete extraction of lead to the metal at the first stage of electrothermal melting, high recovery of Re and Cd into the secondary sublimate and, subsequently to NH₄ReO₄ and cadmium sponge as well as the minimization of huge amounts of sulfate lead cakes.

Conclusions

Experiments on electrothermal processing of lead-containing dusts, using the mathematically modeled test parameters, were performed. The factors of temperature, time, flow rate of soda, sodium sulfate, and a reducing agent (coke) were selected. Separate dependencies, describing the impact of these factors on extraction degree of lead to the metallic phase, copper—to matte-slag melt, cadmium, and rhenium into secondary fumes, were shown. Based on the significant particular dependencies, the compiled multifactor equations were generalized that allowed to calculate the extraction degree of metals to the corresponding intermediates.

The optimal conditions for smelting are as follows: content of Na₂CO₃—40 %, Na₂SO₄—8 %, and coke—10 % by weight of dust at temperature of 1175 °C and exposure duration of 30 min. Under these conditions, the highest rates of Pb extraction to crude metal, Cu, Zn, and As to molten sodium thio-salts and Cd and Re into secondary fumes were observed. The resulting rough lead is refined

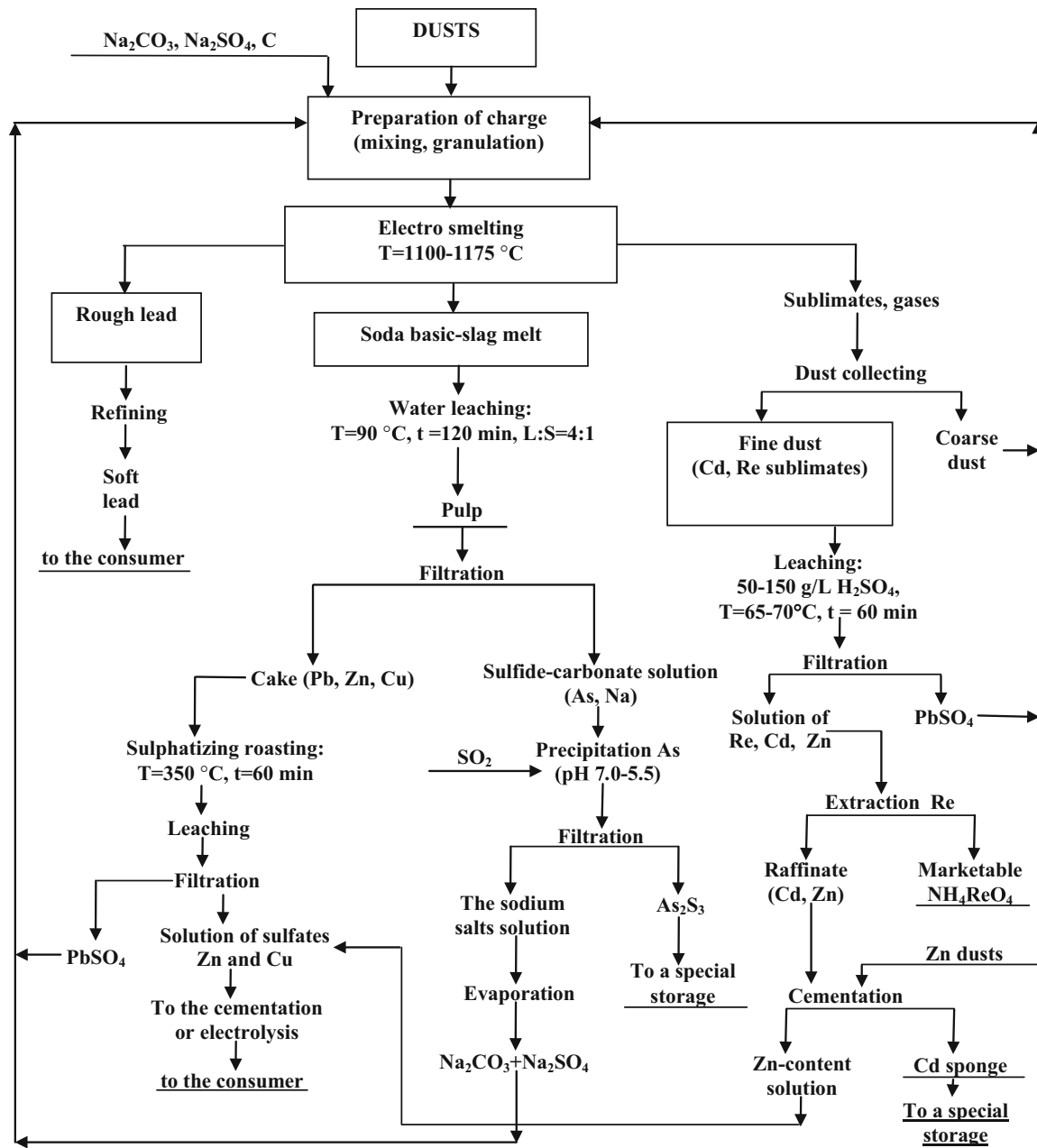
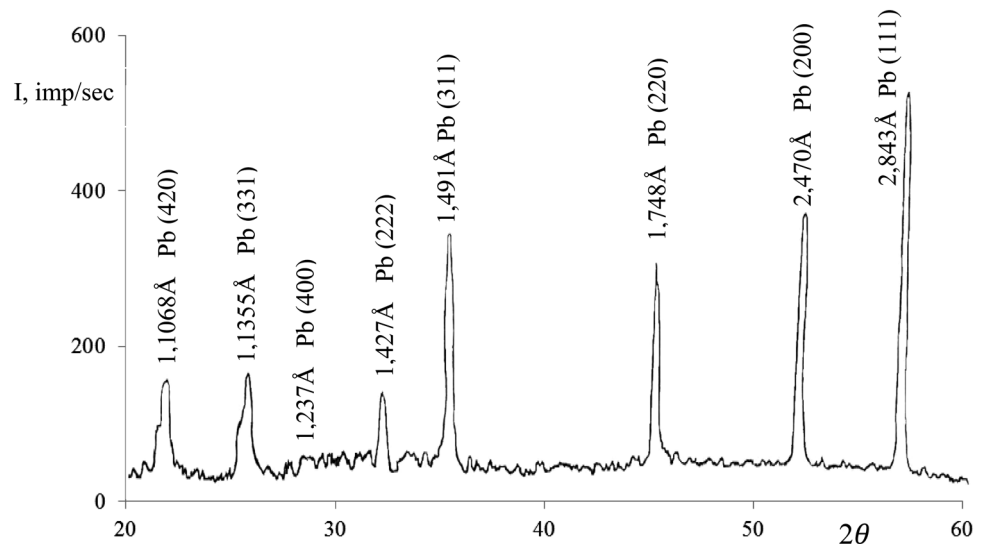


Fig. 4 Flow-sheet for process steps required in the electrosmelting processing of copper-smelter dusts

Fig. 5 XRD pattern of rough lead obtained after electrosmelting of lead-containing dusts of copper smelting production



by a standard scheme, the molten sodium thiosalts, and secondary sublimates are processed by hydrometallurgical methods to recover the respective metals.

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