

Method of Hot-Dip Galvanizing Dross Processing with Obtaining Marketable Products

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Abstract. In the present work we consider the processing of dross by chlorination firing. Based on the thermodynamic analysis of the reactions between the components of the oxide part of the cinders and calcium and ammonium chlorides, the fundamental possibility of obtaining pure zinc oxide suitable for use as mineral additives in animal feed is shown. As a result of thermodynamic calculations of reactions of interaction of impurity metals (Pb, Fe, etc.) with CaCl_2 and NH_4Cl the values of Gibbs free energy and rate constants of reactions in the temperature range 973...1373 K have been determined. It was found that under the conditions of oxidative roasting the reactions of interaction of impurity metals (Pb, Fe, As, Sb) present in the oxide part of the dross with calcium and ammonium chlorides proceed with the formation of their chlorides and sublime. The high Gibbs free energies of chlorination of metals with ammonium chloride show better roasting efficiency than roasting with calcium chloride. The optimum parameters of burning of oxidized fraction of slag have been established: $T=1000^\circ\text{C}$, CaCl_2 consumption – 1,2-1,7 % of stoichiometrically necessary quantity for lead chlorination, NH_4Cl consumption – 1 % of weight of initial oxidized fraction. Pure zinc oxide was obtained with the following composition, % (wt.): 70-73 Zn; 0,02-0,05 Pb; 0,5-1,2 Fe; 0,04-0,08 Cu; 0,001-0,002 Cd; 0,005-0,007 As; 0,005-0,006 Sb; 0,007-0,01 Sn.

Keywords: dross, impurity metals, chlorine firing, thermodynamics, Gibbs free energy, calcium chloride, ammonium chloride, zinc oxide.

Introduction

The problem of metal protection against corrosion is one of the most important technical problems all over the world. Among the large number of known methods of protecting steel structures from corrosion the hot-dip galvanizing is effective, technological and fairly cheap. Zinc coating has a good appearance and allows increasing the service life of products by 2-3 times and reliably protects them from atmospheric and other types of corrosion [1].

The high prices for zinc, which make up the main part of the cost of galvanizing, require the economical use of zinc and the disposal of its waste, one of which is dross. The output of dross is from 0.5 to 3.5% of the mass of the passed products. Dross in its composition is represented by zinc oxide. It contains 30-40% of metallic zinc [2]. The complex chemical composition of the dross makes it difficult to further usage of it. Its main processing in practice is about extraction of the metal part of zinc, which due to its low quality is not commercial product and is used in the process of galvanizing products.

At the same time, the non-metallic part of the dross remaining after the separation of zinc is accumulated and stored at enterprises and plants, occupying large territories, due to the significant content of lead and other impurity metals in it and the lack of rational processing technology on the other hand.

At present, pyrometallurgical methods of ash processing using various reagents (acids, alkaline methods, addition of sodium fluorides, aluminum, etc.) are widespread in practice [3-7]. Hydrometallurgical methods have been developing in recent years [2, 8-10].

One of the most effective methods for processing the dross can be the preliminary separation of the metal and oxide parts of the dross with further separate processing of each of them [11]. The metal part is melted in an induction furnace under a layer of ammonium chloride and charcoal. Metallic zinc is obtained from the metal part with the composition, %: 95.9 Zn; 1.54 Pb; 0.9 Fe; 0.4 Cu.

The oxide part of the dross is subjected to roasting at 800-900°C and zinc oxide is obtained, which is

used for the preparation of whitewash. At the same time, due to the high content of lead (1.2%) and iron (0.95%) in the dross, the quality of the produced whitewash is low.

The disadvantages of this method include: the difficulty of separating the metallic and non-metallic oxide fractions; zinc oxide remains in the metal drops of zinc, which greatly impacts the quality of the produced zinc whitewash.

Despite the indicated disadvantages, the approach proposed in [11] for the preliminary separation of the metal and oxide parts of the dross with further separate processing of each of them seems to be quite effective. At the same time, if the metal part can be used as a material for secondary use in galvanizing, then the investigating the ways to process the non-metallic, oxide part of the dross containing such impurities as Pb, Fe, As, Sb requires additional research.

It has a fundamental importance to study the behavior of lead and iron, in the vision of their high concentrations in the oxide part of the dross which can reach 1.2 and 1%, respectively. The high content of metal impurities in the dross hinders their further sale and use, and leads to accumulation. The results of well-known works on the processing of dross do not give an unambiguous picture of removing impurities.

In this work, based on the study of the behavior of zinc and accompanying impurities (Pb, Fe, As, Sb) under the conditions of chlorinated roasting of the oxide part of the dross with calcium and ammonium chlorides, the fundamental possibility of obtaining pure commercial zinc oxide suitable for use as mineral additives in animal feed is substantiated.

Research methods

A silite heating furnace was used as an experimental equipment for melting the metal fraction of dross. For roasting of oxide fraction of dross – Nabertherm R50/250/12 horizontal electric furnace with temperature controller B410 was used. For melting – alundum crucibles and for roasting – alundum boats (120×60×20 mm) were used as a container for loading the feed materials. The airflow rate during roasting of the oxide fraction of dross with CaCl₂ and NH₄Cl was monitored with RM-GS 004 KL4 rotameter.

Preparation of the samples for chemical analysis was carried out as follows: 10 mg of the material was dissolved in 65% (vol.) nitric acid and then analyzed. Material composition was characterized using an atomic absorption spectrophotometer equipped with a graphite combustion chamber (Perkin Elmer 5100). Powder X-ray diffraction (XRD) was performed on an Ultima III diffractometer (Rigaku Corporation, Japan) with quantitative phase analysis accomplished using Jade₁₀ (MDI, Cal.) software and the ICSD database and energy-dispersive X-ray fluorescence spectroscopy was performed on a LEO Supra scanning electron microscope (SEM).

Each sample obtained after the experiments was subjected to the elemental composition twice. The final elemental composition was determined based on the average value obtained from the results of two independent measurements.

For a better understanding of the mechanism of chlorinating roasting, a detailed thermodynamic analysis of the interaction of dross components with chlorinating reagents (CaCl₂ and NH₄Cl) was carried out.

Results and discussion

Thermodynamic analysis of the reactions of chlorination of zinc, impurity metals and their oxides with calcium and ammonium chlorides

The model of thermodynamic reactions of chlorination of the components of the metal fraction with ammonium chloride (melting) and the oxidized fraction of dross (roasting) with calcium and ammonium chloride is considered from the standpoint of the above results of mineralogical studies of the phase composition of the initial products.

The mechanism of the chlorination process can be described by a system of reactions typical for the conditions of melting the metal fraction of dross with ammonium chloride and roasting the oxidized fraction with CaCl₂ and NH₄Cl, shown in Table 3.

The probable direction of the reactions was estimated by the change in the thermodynamic values of the system. Thermodynamic calculations were conducted by calculating the Gibbs free energy (ΔG°_T) of reactions and establishing their dependence on temperature.

As the standard state of zinc, impurity metals and their oxides the pure solid metal (Me_s) and solid oxide (MeO_s) is taken. For metal chlorides the pure MeCl_{2(g)} is considered. For the calculations the reference data from [12].

The results of thermodynamic calculations are summarized in Table 1.

It was found that the course of interaction reactions between metal oxides MeO (Me – Zn, Pb, Fe, Cu, Ni, Cd) and CaCl₂ in the entire investigated temperature range is impossible, due to the positive values of the Gibbs free energy.

During the roasting active chlorination of metallic zinc with calcium chloride according to reaction (1) is expected. In the temperature range 673-1373 K, the Gibbs free energy of reaction (1) shows a decrease with increasing temperature: from $\Delta G_{673\text{K}} = -189.1$ kJ/mol to $\Delta G_{1373\text{K}} = -123.7$ kJ/mol. Nevertheless, the high negative values of the Gibbs free energy indicate the possibility of the formation of gaseous zinc chloride and solid calcium oxide in the cinder over the entire investigated temperature range.

Zinc chloride formed as a result of reaction (1) does not interact with atmospheric oxygen according to reaction (2), due to the positive values of Gibbs free energy in the entire investigated temperature range of 673-1373 K.

Table 1 – Calculated values of the Gibbs free energy of the reactions of chlorination of zinc, impurity metals and their oxides with calcium and ammonium chlorides

No	Reaction	Temperature, K							
		673	773	873	973	1073	1173	1273	1373
		ΔG, kJ/mol							
(1)	$Zn + CaCl_2 + 0,5O_2 = ZnCl_2 + CaO$	-189,1	-180,6	-172,21	-164,07	-155,4	-144,8	-134,2	-123,7
(2)	$ZnCl_2 + 0,5O_2 = ZnO + Cl_2$	31,5	28,9	26,7	24,8	23,2	21,9	20,8	19,9
(3)	$Pb + CaCl_2 + 0.5O_{2(g)} = PbCl_2 + CaO$	-67,6	-74,5	-81,2	-87,9	-93,6	-97,2	-100,5	-103,6
(4)	$Fe + 1.5CaCl_2 + 0.75O_{2(g)} = FeCl_3 + 1.5CaO$	-65,4	-51,9	-38,5	-25,2	-10,6	7,3	25,4	43,7
(5)	$Cu + CaCl_2 + 0.5O_{2(g)} = CuCl_2 + CaO$	3,7	11,4	18,7	25,7	33,1	42,1	50,9	59,7
(6)	$Ni + CaCl_2 + 0.5O_{2(g)} = NiCl_2 + CaO$	-77	-67,03	-57,14	-47,32	-36,78	-24,21	-11,54	-2,96
(7)	$Cd + CaCl_2 + 0.5O_{2(g)} = CdCl_2 + CaO$	-160,51	-150,58	-142,33	-136,94	-131,1	-123,5	-116	-108,65
(8)	$ZnCl_2 + Pb + 0.5O_{2(g)} = PbCl_2 + ZnO$	-162,04	-166,86	-171,3	-175,4	-179,2	-182,7	-186	-189,2
(9)	$3ZnCl_2 + 2Fe + 1.5O_{2(g)} = 2FeCl_3 + 3ZnO$	-414,1	-380,91	-347,16	-312,95	-277,9	-242	-205,7	-136,26
(10)	$ZnCl_2 + Cu + 0.5O_{2(g)} = CuCl_2 + ZnO$	-90,7	-80,9	-71,23	-61,73	-52,43	-43,36	-34,55	-25,84
(11)	$ZnCl_2 + Ni + 0.5O_{2(g)} = NiCl_2 + ZnO$	-171,42	-159,39	-147,18	-134,81	-122,3	-109,7	-97,09	-88,53
(12)	$ZnCl_2 + Cd + 0.5O_{2(g)} = CdCl_2 + ZnO$	-254,93	-242,93	-232,36	-224,44	-216,6	-209	-201,5	-194,23
(13)	$Zn + 2NH_4Cl + 0.5O_{2(g)} = ZnCl_2 + 2NH_{3(g)} + H_2O_{(g)}$	-249,52	-279,21	-309,16	-339,55	-370,3	-401,6	-433,2	-465,27
(14)	$ZnO + 2NH_4Cl = ZnCl_2 + 2NH_{3(g)} + H_2O_{(g)}$	-81,99	-133,48	-186,03	-239,54	-293,9	-349,1	-405	-461,67
(15)	$Pb + 2NH_4Cl + 0.5O_{2(g)} = PbCl_2 + 2NH_{3(g)} + H_2O_{(g)}$	-244,03	-300,35	-357,33	-414,94	-473,1	-531,8	-591,1	-650,87
(16)	$Fe + 3NH_4Cl + 0.75O_{2(g)} = FeCl_3 + 3NH_{3(g)} + 1.5H_2O_{(g)}$	-330,04	-390,68	-452,63	-515,79	-579,8	-644,6	-710,4	-777,13
(17)	$Cu + 2NH_4Cl + 0.5O_{2(g)} = CuCl_2 + 2NH_{3(g)} + H_2O_{(g)}$	-172,7	-214,39	-257,27	-301,28	-346,3	-392,4	-439,5	-487,51
(18)	$Ni + 2NH_4Cl + 0.5O_{2(g)} = NiCl_2 + 2NH_{3(g)} + H_2O_{(g)}$	-253,42	-292,88	-333,21	-374,36	-416,2	-458,8	-502,1	-550,21
(19)	$Cd + 2NH_4Cl + 0.5O_{2(g)} = CdCl_2 + 2NH_{3(g)} + H_2O_{(g)}$	-336,93	-376,42	-418,4	-463,9	-510,5	-558,1	-606,6	-655,9
(20)	$PbO + 2NH_4Cl = PbCl_2 + 2NH_{3(g)} + H_2O_{(g)}$	-157,17	-206,56	-259,76	-314,03	-369,2	-425	-479,6	-534,97
(21)	$Fe_2O_3 + 6NH_4Cl = 2FeCl_3 + 6NH_{3(g)} + 3H_2O_{(g)}$	-24,53	-173,18	-324,18	-477,23	-632,2	-789,2	-948,1	-1108,8
(22)	$CuO + 2NH_4Cl = CuCl_2 + 2NH_{3(g)} + H_2O_{(g)}$	-78,92	-129,27	-180,67	-233,07	-286,4	-340,6	-395,7	-451,75
(23)	$NiO + 2NH_4Cl = NiCl_2 + 2NH_{3(g)} + H_2O_{(g)}$	-74,82	-122,97	-171,92	-221,62	-272	-323	-374,7	-431,15
(24)	$CdO + 2NH_4Cl = CdCl_2 + 2NH_{3(g)} + H_2O_{(g)}$	-144,47	-194,53	-247	-302,99	-359,9	-417,7	-476,4	-535,83

Thus, it can be argued that under conditions of joint roasting of the oxide fraction of dross with CaCl₂ in an oxidizing atmosphere, favorable conditions are created for the conversion of metallic zinc into oxide. From a practical point of view, this will lead to an increase in the content of zinc oxide, and, as a result, improve the quality of the final product (ZnO).

For the melting of the metal fraction, the use of calcium chloride does not seem to be effective, due to the favorable conditions being created for the conversion of metallic zinc into its oxide. This will have a significant effect on reducing the quality of the resulting metal zinc ingot.

The interaction of impurity metals with CaCl₂ is described by a group of reactions (3)-(7). At the temperature of melting (673 K) and roasting (1373 K), all reactions, except for reaction (5), are characterized by negative values of Gibbs free energy. High negative values of ΔG°_T are typical for reactions (3), (6) and (7), which indicates a deep sublimation of lead, nickel and cadmium, both during the melting of the metal fraction and during the roasting of the oxidized fraction.

Under roasting conditions, the possibility of the interaction of impurity metals with zinc chloride formed by reaction (1) is not excluded. The

mechanism of interaction of impurity metals with $ZnCl_2$ is described by the course of reactions (8)-(12). The results of thermodynamic calculations show large negative values of the Gibbs free energy of reactions (8)-(12).

The high probability of reactions (8)-(12) indicates their priority over reactions (2), (3)-(7), which describe the direct chlorination of impurity metals with calcium chloride. The course of reactions (8)-(12) creates favorable conditions for the deep sublimation of impurity metals in the form of their chlorides, which significantly affects the improvement of the quality of the resulting zinc oxide.

The mechanism of roasting of oxide fraction of dross with ammonium chloride (Table 1) is described by a group of reactions (13)-(24). Large negative values of the Gibbs free energy of reactions (13)-(24) show a high probability of their occurrence and contribute to the production of purer zinc oxide due to the deep sublimation of impurity metals in the form of their chlorides. The values of the Gibbs free energy of reactions (13)-(24) are much higher than the values of ΔG°_T for reactions (3)-(7) (Table 1).

The obtained results indicate the preference and higher efficiency of melting the metal fraction of dross with ammonium chloride than with calcium chloride. The choice and justification of one or another chlorinating reagent for each specific process (melting, roasting) should be determined on the basis of the results of experimental tests to study the effect of their consumption on the sublimation depth of impurity metals from both the metal fraction of the dross and the oxidized fraction.

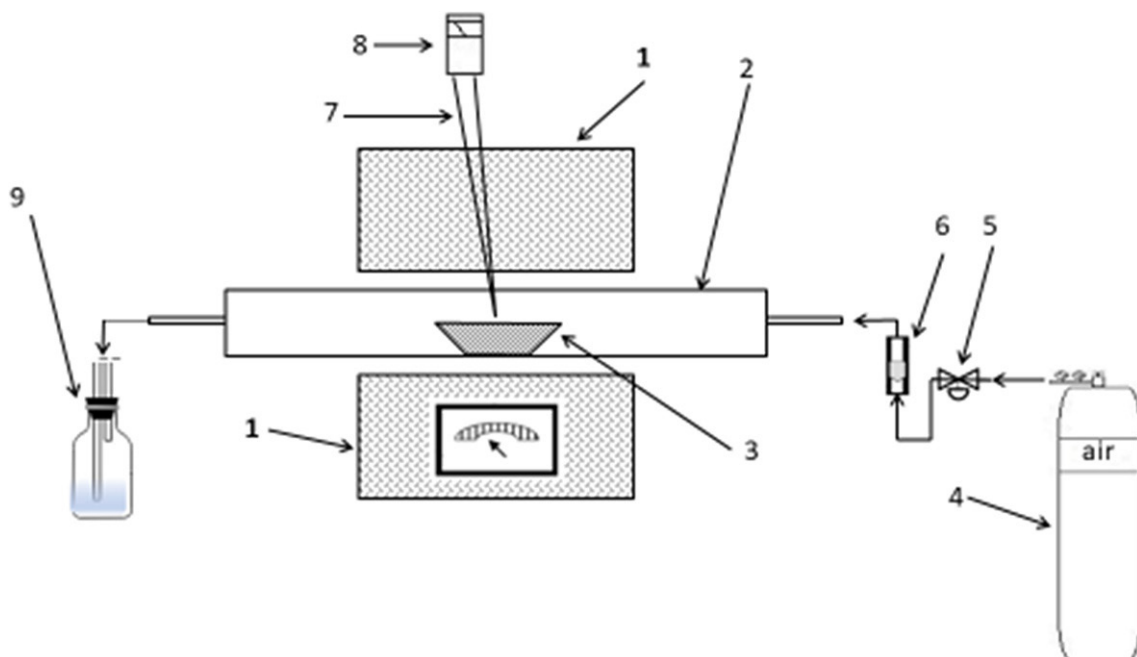
Firing of oxidized dross fraction using $CaCl_2$ and NH_4Cl

The essence of the experiments was as follows. Preliminary ash was crushed in a ball mill. The milled material of the initial dross was subjected to the sieve analysis with separation of the coarse metal fraction (0.7÷1.0 mm) and the fine oxidized fraction (100 mesh). The coarse fraction, consisting of metallic zinc, was sent for smelting under a layer of flux (NH_4Cl) by the known methods for obtaining pure zinc ingots. The fine non-metallic oxidized fraction was sent for chlorination firing.

Scheme of the installation to research the effect of the consumption of chlorinating reagents ($CaCl_2$, NH_4Cl) and temperature on the production of commercial zinc oxide, suitable for use as mineral additives in feed for animals and birds, is shown in figure.

The oxide fraction of the dross after hot-dip galvanizing was mixed with a given rate of calcium chloride, ammonium chloride in various mass ratios. The mixture was held in an aluminum oxide crucible inside the furnace, which was heated, and then held at a given temperature in a stream of air, which was fed at a rate of 100 ml/min. Exhaust gases from the furnace were absorbed in a gas absorption vessel. After settling and cooling in the air flow, the crucible was removed from the furnace and broken. The end product (cinder) was weighed and analyzed according to the methods described above.

The initial product (oxidized fraction) contained 15% metallic zinc and 0.8% lead. In all experiments, the weight of the initial product was constant and was



1 – Nabertherm R50/250/12 electric furnace with temperature controller B410; 2 – quartz reactor; 3 – alumina boat with sample; 4 – air cylinder; 5 – valve; 6 – rotameter RM-GS 004 KL4; 7 – thermocouple PP-1; 8 – secondary device KSP-4; 9 – a vessel for absorbing gases

Laboratory setup scheme

100 g. The roasting charge was a mixture consisting of the initial product (dross), chlorine-containing reagents (CaCl₂, NH₄Cl) and quartz flux (SiO₂). The firing temperature was 750-1150°C. Firing duration in all experiments was constant at 60 min.

The results of the experiments are presented in Table 2.

The best results were achieved at a firing temperature of 1000°C. Optimal consumption of reagents: CaCl₂ – 1,2-1,7% of stoichiometrically necessary quantity for lead chlorination; NH₄Cl consumption – 1% of weight of initial zinc oxide fraction. Composition of pure zinc oxide, obtained after chlorination firing of oxide fraction, is following, % (wt.): 70-73 Zn; 0,02-0,05 Pb; 0,5-1,2 Fe; 0,04-0,08 Cu; 0,001-0,002 Cd; 0,005-0,007 As; 0,005-0,006 Sb; 0,007-0,01 Sn (experiments №7-12). The obtained product is suitable for use as a mineral additive in the feed of domestic animals and birds.

Conclusions

A new method of obtaining pure metallic zinc and zinc oxide from hot dip galvanizing dross by chlorination of previously separated oxidized and non-metallic fractions is presented. The results of thermodynamic calculations show that the use of CaCl₂ and NH₄Cl as chlorinating reagents allows to obtain commodity metal zinc and pure zinc oxide by

deep reduction of impurity metals.

The results on the influence of CaCl₂ and NH₄Cl consumption on the degree of sublimation of impurity metals in the firing conditions in the temperature range of 750-1000°C have been obtained. It is established that the use of CaCl₂ as a chlorinating reagent provides deep purification of the initial material from Pb, Fe, Cu, Ni, Cd. At the same time the maximum reduction of iron content is not possible. It is shown that the use of NH₄Cl as a chlorinating reagent, although it provides deep removal of metal impurities, the reduction of lead content is not achieved: the lead content in the slag remains at 0.12%.

The best solution seems to be the simultaneous use of CaCl₂ and NH₄Cl. The optimum firing parameters have been established: T=1000°C, duration – 60 min, air flow rate – 0,1 l/min. By that, pure zinc oxide of composition, % (wt.): 70-73 Zn; 0,02-0,05 Pb; 0,5-1,2 Fe; 0,04-0,08 Cu; 0,001-0,002 Cd; 0,005-0,007 As; 0,005-0,006 Sb; 0,007-0,01 Sn was received.

The technology has the following advantages:

Processing is carried out in parallel to the main technological chain of the factory production with the elimination of tense modes in it when changing the composition of raw materials;

1. The technology allows separate processing

Table 2 – Results of experiments on the processing of the oxide fraction of dross

No	Quantity Oxidized fraction, g	Reagent consumption, fractions of more than 1 of stoichiometry		Firing temperature, °C	The content of Me, % by weight.	
		CaCl ₂	NH ₄ Cl		Zn	Pb
1	100	0	0	1000	14	0,75
2	100	0	0,5	1000	12	0,77
3	100	0	1,0	1000	6	0,8
4	100	0	2,0	1000	5	0,8
5	100	0	3,0	1000	4	0,79
6	100	1,1	0,4	1000	0,1	0,08
7	100	1,2	0,5	1000	0,05	0,02
8	100	1,3	0,7	1000	0,05	0,02
9	100	1,4	1,0	1000	0,05	0,02
10	100	1,5	1,5	1000	0,05	0,02
11	100	1,6	1,5	1000	0,05	0,02
12	100	1,7	1,5	1000	0,05	0,02
13	100	1,8	1,6	1000	0,06	0,03
14	100	1,4	1,0	750	0,2	0,8
15	100	1,4	1,0	800	0,1	0,4
16	100	1,4	1,0	1100	0,05	0,01*)
17	100	1,4	1,0	1100	0,05	0,01*)
18	100	1,4	1,0	1150	0,2	0,5**)

*) – the material began to sinter; **) – the material is sintering.

of metallic and non-metallic part of slag after their preliminary separation with obtaining metallic zinc ingot and zinc oxide powder of high quality.

2. The complexity of slag processing with high

extraction of valuable components (zinc, zinc oxide, lead) in the target products is ensured.

3. Simplicity, reliability, environmental safety and durability of the equipment design.

Intellectual property is protected by a Republic of Kazakhstan patent: «Method of hot dip galvanizing dross processing» // Patent Republic of Kazakhstan No. 34231, Bulletin No. 11 of 20.03.2020. Authors: Dosmukhamedov N.K., Kaplan V.A., Zholdasbay E.E., Kaplan A.V.

Acknowledgments

The research was carried out within the framework of grant funding of the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan for 2021-2023 in the priority area «Rational use of water resources, flora and fauna, ecology» project No. AP09058297 «Development of a new waste-free technology for the disposal of hot-dip galvanized wastes with complex extraction of valuable components».

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Тауар өнімдерін ала отырып, ыстықтай мырышталған күйіктерді өңдеу тәсілі

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Аңдатпа. Бұл жұмыста күйіндіні хлорлап күйдіру арқылы өңдеу мәселесі қарастырылған. Күйіндінің тотыққан бөлігінің компоненттерімен кальций мен аммоний хлориді арасындағы өзара әрекеттесу реакцияларын термодинамикалық талдауы негізінде жануарлардың жеміне минералды қоспалар ретінде пайдалануға жарамды таза мырыш тотығын алудың негізгі мүмкіндігі көрсетілген. 973...1373 К температуралық аралықта қоспа металдардың (Pb, Fe және т.б.) CaCl_2 және NH_4Cl өзара әрекеттесу реакцияларының термодинамикалық есептеулерінің нәтижесінде еркін Гиббс энергиясының мәні және реакциялар жылдамдығының константалары анықталды. Тотықтырып күйдіру жағдайында күйіндінің тотықты бөлігінде болатын қоспа металдардың (Pb, Fe, As, Sb) кальций мен аммоний хлоридтерімен әрекеттесу реакциялары жүру нәтижесінде

олардың хлоридтерінің қалыптасуы және ұшуы анықталды. Металдарды аммоний хлоридімен хлорлаудың еркін Гиббс энергиясы мәні кальций хлоридімен күйдіруге қарағанда жоғары және тиімді екендігін көрсетті. Күйіндінің тотықты фракциясын күйдірудің оңтайлы параметрлері белгіленді: $T=1000^{\circ}\text{C}$, қорғасынды хлорлау үшін оның стехиометриялық қажетті мөлшерінен CaCl_2 шығыны – 1,2-1,7%, бастапқы тотықты фракцияның салмағынан NH_4Cl шығыны – 1%. Келесі құрамдағы таза мырыш тотығы алынды, % (масса.): 70-73 Zn; 0,02-0,05 Pb; 0,5-1,2 Fe; 0,04-0,08 Cu; 0,001-0,002 Cd; 0,005-0,007 As; 0,005-0,006 Sb; 0,007-0,01 Sn.

Кілт сөздер: күйінді, қоспа металдар, хлорлап күйдіру, термодинамика, еркін Гиббс энергиясы, кальций хлориді, аммоний хлориді, мырыш тотығы.

Способ переработки изгари горячего оцинкования с получением товарных продуктов

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Аннотация. В настоящей работе рассматривается вопрос переработки изгари путем хлорирующего обжига. На основании термодинамического анализа реакций взаимодействия между компонентами оксидной части изгари и хлоридами кальция и аммония показана принципиальная возможность получения чистого оксида цинка, пригодного для использования в качестве минеральных добавок в корм животных. В результате термодинамических расчетов реакций взаимодействия металлов-примесей (Pb, Fe и др.) с CaCl_2 и NH_4Cl определены значения свободной энергии Гиббса и констант скорости реакций в температурном интервале 973...1373 К. Установлено, что в условиях окислительного обжига протекают реакции взаимодействия примесных металлов (Pb, Fe, As, Sb), присутствующих в оксидной части изгари, с хлоридами кальция и аммония с образованием их хлоридов и улетучиванием. Высокие значения свободной энергии Гиббса хлорирования металлов хлоридом аммония показывают лучшую эффективность обжига, чем обжиг с хлоридом кальция. Установлены оптимальные параметры обжига окисленной фракции изгари: $T=1000^{\circ}\text{C}$, расход CaCl_2 – 1,2-1,7% от стехиометрически необходимого его количества для хлорирования свинца, расход NH_4Cl – 1% от веса исходной окисленной фракции. Получен чистый оксид цинка следующего состава, % (масса.): 70-73 Zn; 0,02-0,05 Pb; 0,5-1,2 Fe; 0,04-0,08 Cu; 0,001-0,002 Cd; 0,005-0,007 As; 0,005-0,006 Sb; 0,007-0,01 Sn.

Ключевые слова: изгарь, металлы-примеси, хлорирующий обжиг, термодинамика, свободная энергия Гиббса, хлорид кальция, хлорид аммония, оксид цинка.

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