

# Smelting a Zn – Pb Sulfide Ore with Magnetite and Carbon for the Production of a Silicon Alloy and Extraction of Zinc and Lead into Sublimates

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## Abstract

The article presents the results of thermodynamic prediction and electric smelting of Shalkiya sulfide zinc-lead-bearing ore in the presence of magnetite and coke. Using the HSC-6.0 software package, it was found that under equilibrium conditions in the presence of  $\text{Fe}_3\text{O}_4$  and carbon, the reduction and formation of gaseous zinc from ZnS (according to  $\Delta G^\circ = 0$ ) occurs at a temperature of 1205.7 °C, and the formation of ferroalloy at the interaction of the sulfide ore with magnetite and carbon begins at 1200 °C. About 58% of silicon is extracted into the ferroalloy at 1800–1900 °C; almost all zinc and 83–88% of lead turns into a gaseous state. Electric smelting of the sulfide ore in the presence of magnetite concentrate and coke makes it possible to obtain the FS45 grade ferrosilicon (42–43% of Si); the silicon extraction degree was 84–88%. At the same time, 97.3% of lead and 99.2% of zinc are extracted into the sublimates. The developed method for processing zinc sulfide ores allows us to increase the degree of raw materials' comprehensive use due to the extraction of not only zinc and lead, but also silicon. The technology can be used to process raw materials containing zinc, lead and silica, such as zinc ore concentration tailings.

## Keywords

electric smelting, ferrosilicon, magnetite, metals' sublimation, sulfide ore, thermodynamic study

## 1 Introduction

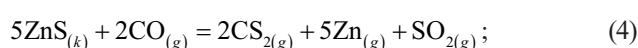
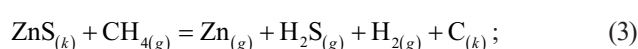
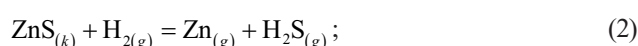
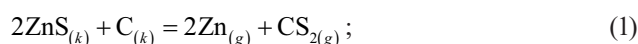
The main source of industrial production of zinc is sulfide ores [1–5], which are processed according to the scheme: crushing, grinding, concentration, roasting of the concentrate, leaching of the cinder, purification of the solution, electrolytic deposition of zinc [6–10]. This scheme has a number of disadvantages, in particular:

- the technology is multistage;
- the concentration of ores, based on the difference in physical and physicochemical properties of granules of individual minerals, ensures the achievement of satisfactory results only when the ore's crushing and grinding processes makes it possible to obtain relatively homogeneous grains of ore minerals that differ in their properties from waste rock minerals [11–13]. This task is quite difficult; therefore, for example, during the Shalkiya ore's concentration, only 70% of zinc and 50% of lead pass into the concentrate [14];

- the scheme becomes inefficient when processing of raw materials with high  $\text{SiO}_2$  content. Such raw materials increase the formation degree of zinc silicates during the roasting; they dissolve easily in sulfuric acid and form colloidal silicic acid ( $\text{H}_2\text{SiO}_3$ ), which makes the subsequent thickening and filtering of the resulting solutions difficult [15];
- low degree of the raw materials' comprehensive use as 30–50% of zinc and lead and almost all non-metallic components of the ores pass into the resulting flotation tailings. (For this reason, there are additional problems associated with the processing and disposal of concentration tailings (as well as leaching tailings) of not only zinc ores but also other ores [16–22]). In recent years, various methods and schemes have been introduced into the lead-zinc ores concentration technology to improve its efficiency

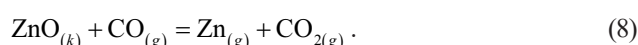
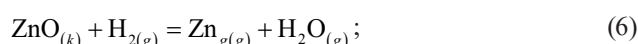
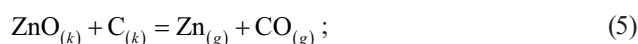
and to increase the complexity of the use of the raw materials [23–26].

The direct reduction of sulfides makes it possible to simplify the processing of sulfide ores. However, the reduction of zinc from ZnS to zinc metal using hydrogen, carbon or carbon monoxide occurs at rather high temperatures [15]. In particular, the reduction of zinc according to the reactions:



where (g) refers to gas phase, and (k) is the condensed phase.  $\Delta G^\circ = 0$  occurs at 1619.8 °C, 1722.0 °C, and 1597.2 °C, respectively, and the formation of zinc in accordance with reaction 4 does not occur even at 2000 °C (Table 1).

In this regard, the sulfide raw materials before their reduction are subjected to roasting to obtain ZnO, and then ZnO is reduced to Zn [15]. This process takes place at a much lower temperature (Table 2):



**Table 1** Effect of temperature on  $\Delta G^\circ$  (kJ/mol) for zinc reduction from ZnS

Reaction	Temperature, °C					
	1300	1400	1600	1700	1800	2000
1	125.5	86.0	7.7	-31.2	-69.8	-141.6
2	60.3	45.8	17.0	2.8	-11.3	-36.8
3	38.8	-1.1	-80.2	-119.3	-158.6	-231.0
4	576.7	502.5	355.3	282.2	209.7	78.2

\*  $\Delta G^\circ$  was calculated using the Reaction Equations option of the HSC-6.0 program [27]

**Table 2** Effect of temperature on  $\Delta G^\circ$  (kJ/mol) for zinc reduction from ZnO

Reaction	Temperature, °C							
	900	1000	1200	1300	1400	1600	1800	2000
5	14.0	-15.1	-73.0	-101.7	-130.2	-186.8	-242.9	-297.6
6	46.4	31.5	16.8	2.20	-12.2	-54.7	-82.5	-100.1
7	68.8	-1.0	-139.3	-207.8	-275.8	-343.4	-474.4	-673.2
8	48.9	37.1	25.3	2.0	-9.5	-32.3	-54.9	-76.3

The beginning temperatures of reactions 5–8 are 948.8; 1315.3; 998.6 and 1317.4 °C, respectively. This is significantly less than the beginning temperature of reduction of Zn from ZnS. The efficiency of the processing of lead-zinc sulfide silica-containing ores can be increased if, according to the proposed method, the direct zinc and lead reduction from the ores is carried out with multifunctional reagents.

The article contains the results of studies on the reduction of metals from the lead-zinc sulfide silica-containing ore in the presence of  $\text{Fe}_3\text{O}_4$  and carbon to obtain a silicon-containing alloy.

## 2 Methods and materials

### 2.1 Methods

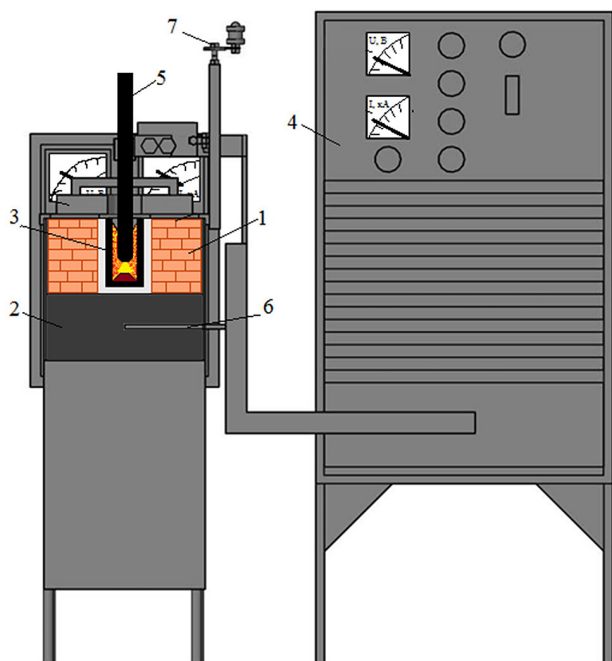
The studies included the computer thermodynamic modeling of the processes and the electric melting of the ore in an arc furnace. The thermodynamic modeling was carried out using the Equilibrium Compositions program of the HSC-6.0 software package [27] developed by the Finnish metallurgical company Outokumpu. The HSC-6.0 database contains information about more than 17,000 chemicals. The HSC Chemistry program, intended for calculating equilibrium, is based on the principle of minimizing the Gibbs energy of a thermodynamic system. The determination of the equilibrium distribution degrees of the elements in the systems under study was implemented according to the algorithm developed at the South Kazakhstan University [28].

The electric smelting of a charge was carried out in an AC single-electrode arc furnace (with power of up to 15 kVA) lined with chromium-magnesite bricks (Fig. 1).

The bottom electrode was made of a graphite block. A graphite crucible ( $d = 6$  cm,  $h = 12$  cm) was placed on the hearth. The upper part of the furnace was closed with a removable lid with holes for the graphite electrode (diameter 3 cm) and gas outlet. The crucible was preliminarily heated by an arc for 30–35 min. During the heating, the electric current was 250–350 A, and voltage was 40–50 V. The first charge portion (200–250 g) was loaded into the heated crucible and melted for 3–6 min. Then, every 4–6 min, the 200–250 g charge portions were additionally



(a)



(b)

**Fig. 1** Single-electrode electric arc furnace: (a) photo, (b) sketch:  
1 – chromium-magnesite lining, 2 – carbon graphite hearth,  
3 – graphite crucible, 4 – transformer TDZhF-1002, 5 – graphite  
electrode, 6 – lower current lead, 7 – electrode movement mechanism

loaded. During the melting period, the electric current was 400–450 A; the voltage was 25–30 V. Electricity was supplied to the furnace from a TDZhF-1002 transformer. The required power was maintained by a thyristor regulator. After the end of the electric smelting, the furnace was cooled for 6–7 h. The graphite crucible was removed from the furnace and broken. The resulting ferroalloy was weighed and analyzed to determine the metals

on an AASnovAA800 atomic absorption spectrometer (Germany) and a JSM-6490LV scanning electron microscope (Japan). To analyze the alloy on the spectrometer, it was preliminary ground to a particle size of <0.1 mm. Then the solid sample was weighted in a crucible and analyzed.

The ferroalloy's density was determined by pycnometric method. The density of the ferrosilicon was determined on a pycnometer in accordance with State Standard 22524-77 using kerosene as a working fluid. The mass of the analyzed ferrosilicon (fraction of 2–3 mm) sample was 30 g. The density was determined by dividing 30 g by the volume of displaced kerosene. Then, on the base of the density, the silicon content in the alloy was calculated. The sublimes for the analysis were taken from the surface of the electric holder. The sublimes were analyzed by the trilonometric method.

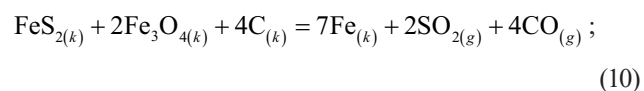
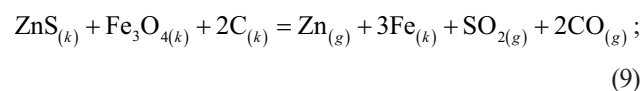
## 2.2 Materials

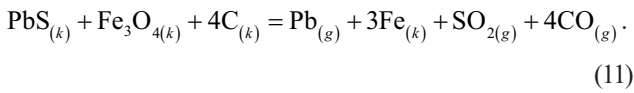
At the thermodynamic modeling, the amounts of magnetite and carbon were 31.5% and 29% of the ore's weight, respectively. It is 100% of the theoretically required amount for the reduction of Si from  $\text{SiO}_2$  and interaction of  $\text{Fe}_2\text{O}_3$  with zinc, iron and lead sulfides in the presence of carbon. The object of study was a sulfide ore with the following composition: 5.2% of ZnS; 1% of PbS; 4.0% of  $\text{FeS}_2$ ; 50% of  $\text{SiO}_2$ ; 6.6% of  $\text{Al}_2\text{O}_3$ ; 19.5% of  $\text{CaCO}_3$ ; 10.1% of  $\text{MgCO}_3$ ; 3.6% of  $\text{Fe}_2\text{O}_3$ ; 0.7% of  $\Sigma\text{Na}_2\text{O}_4 + \text{K}_2\text{O}$ . The electric smelting of the Shalkiya ore was performed using a magnetite concentrate produced from the copper ores' flotation tailings at the "Iron Concentrate Company" LLP (Balkhash, Kazakhstan) [29]. The composition of the magnetite concentrate: 85.9% of  $\text{Fe}_3\text{O}_4$ ; 9.0% of  $\text{SiO}_2$ ; 2% of CaO; 1.4% of  $\text{Al}_2\text{O}_3$ ; 0.3% of MnO; 0.3% of  $\text{K}_2\text{O}$ ; 0.2% of  $\text{Na}_2\text{O}$ ; 0.4% of MgO; 0.2% of ZnO; 0.4% of PbO.

Coke, used for carrying out the smelting, contains 87.2% of C; 1.0% of volatiles; 0.85% of S; 10.0% of ash (2.5% of  $\text{SiO}_2$ , 1.4% of  $\text{Al}_2\text{O}_3$ , 0.4% of  $\text{Fe}_2\text{O}_3$ , 0.1% of (CaO + MgO)) and steel shavings obtained from carbon steel with the following composition: Fe – 97.4%, C – 1.8%, Si – 0.4%, Mn – 0.3%,  $\Sigma(\text{S} + \text{P})$  – 0.1%.

## 3 Research results

At the first stage of the research,  $\Delta G^\circ$  of the sulfides and  $\text{Fe}_3\text{O}_4$  interaction was determined using the reactions:





The effect of temperature on  $\Delta G^\circ$  of the reactions is shown in Table 3.

Reaction 9 becomes possible at 1205.7 °C, reaction 10 at 1238.8 °C, and reaction 11 at 1192.8 °C. Comparing the data in Tables 1 and 3, it can be seen that the possible reduction temperature of Zn from ZnS in the presence of  $\text{Fe}_3\text{O}_4$  decreases by 414.1 degrees (from 1619.8 to 1205.7 °C). The results obtained were the reason for a deeper thermodynamic analysis of the interaction of ZnS with  $\text{Fe}_3\text{O}_4$  and carbon by means of computer thermodynamic simulation using the HSC-6.0 software package.

Figs. 2 and 3 show the equilibrium quantitative distribution of zinc and iron in the  $\text{ZnS} - \text{Fe}_3\text{O}_4 - 2\text{C}$  system at a pressure of 1 bar. As it follows from Figs. 2 and 3, the reduction of zinc from ZnS begins at 1200 °C. Zinc is formed in a gaseous state. At temperatures >1600 °C, the formation of secondary ZnS (gaseous) takes place in the system.

The process of iron distribution is more complicated. So, iron at 600–1200 °C is in the form of  $\text{Fe}_3\text{O}_4$ , FeO, Fe and  $\text{Fe}_2\text{O}_3$ . At temperatures above 1200 °C, the formation of secondary  $\text{FeS}_2$  begins. A noticeable (>1%) transition of zinc to the gaseous state occurs at temperatures above 1200 °C.

Table 4 shows the equilibrium distribution degree of zinc. It can be seen that the most of zinc (88–91%) passes into gas at 1800–2000 °C. The incomplete transition of Zn into gas is associated with the development of the ZnS evaporation process at a temperature of more than 1500 °C. The total transition degree of zinc and ZnS into gas at 1800 °C is 99.5% (Table 4).

The quantitative distribution of zinc, silicon, lead and iron in the Shalkiya sulfide ore –  $\text{Fe}_3\text{O}_4 - \text{C}$  system is represented in Fig. 4.

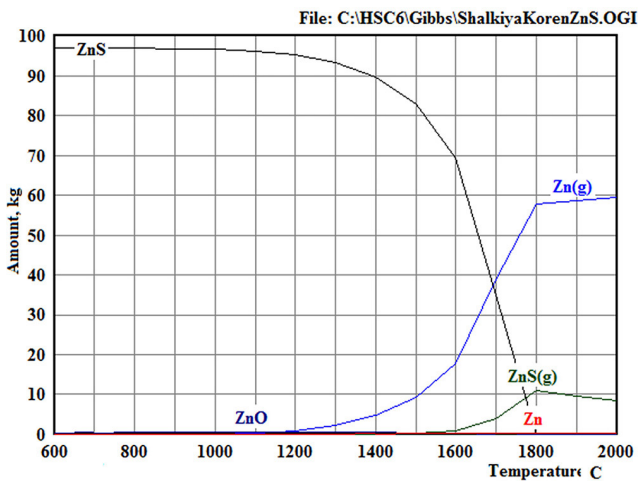
As it follows from Fig. 4, the full reduction of zinc and its transition to a gas phase are completed at 1600 °C. Lead begins to reduce and turn into gas at temperatures above 1100 °C, and this process is not completed until 1900 °C. Iron in the system is formed already at 600 °C, iron silicides  $\text{FeSi}$ ,  $\text{Fe}_3\text{Si}$  are formed at 1200 °C. The formation of  $\text{Fe}_5\text{Si}_3$ ,  $\text{FeSi}_2$  and  $\text{FeSi}_{2.33}$  occurs at higher temperatures. Elemental silicon and  $\text{SiO}_g$  are formed in the system at temperatures above 1500 °C.

The effect of temperature on the equilibrium distribution degree of silicon, zinc and lead in the sulfide ore –  $\text{Fe}_3\text{O}_4 - \text{C}$  system is represented in Fig. 5.

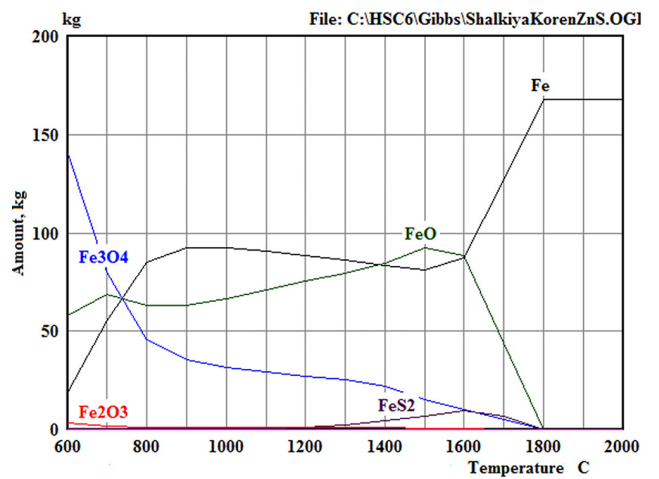
It can be seen that the main part of silicon passes into the ferroalloy as  $\text{FeSi}$  (for example, 47.2% at 1800 °C) and Si (8.4%). Part of the silicon goes into calcium and

**Table 3** The effect of temperature on  $\Delta G^\circ$  (kJ/mol) of the sulfides and  $\text{Fe}_3\text{O}_4$  interaction

Reaction	Temperature, °C									
	1000	1100	1200	1300	1400	1600	1700	1800	1900	2000
9	122.7	62.9	3.4	-55.8	-114.7	-233.4	-286.8	-340.0	-392.1	-443.6
10	27.7	72.1	171.5	-270.4	-368.8	-568.6	-657.4	-746.1	-834.6	-922.9
11	108.1	50.4	-3.9	-57.3	-110.4	-217.3	-264.7	-312.1	-359.1	-406.0



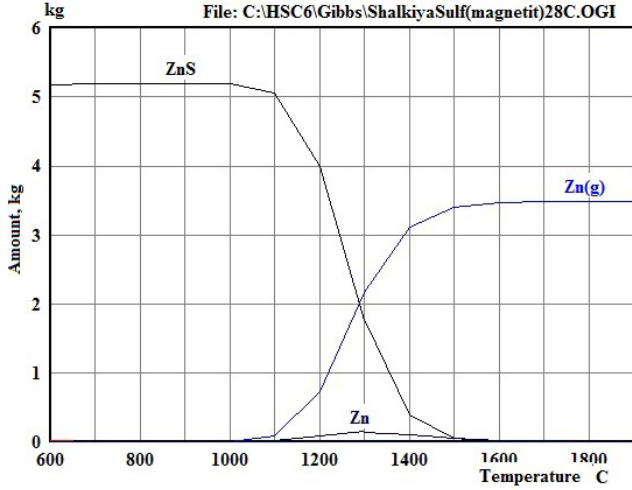
**Fig. 2** Effect of temperature on the quantitative distribution of zinc in the  $\text{ZnS} - \text{Fe}_3\text{O}_4 - 2\text{C}$  system



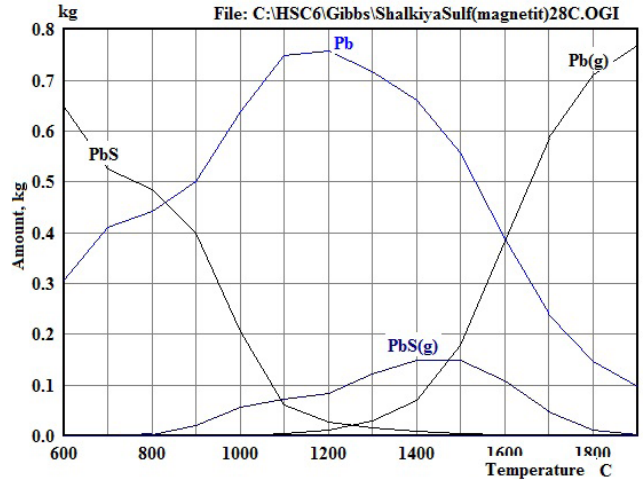
**Fig. 3** Effect of temperature on the quantitative distribution of iron in the  $\text{ZnS} - \text{Fe}_3\text{O}_4 - 2\text{C}$  system

**Table 4** Effect of temperature on the zinc equilibrium distribution degree, %

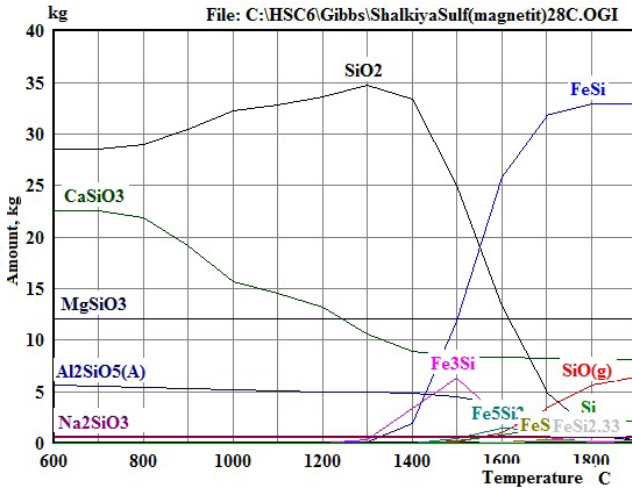
Temperature, °C	ZnS	ZnO	Zn	Zn <sub>(g)</sub>	ZnS <sub>(g)</sub>	Σ Zn <sub>(g)</sub> and ZnS <sub>(g)</sub>
1600	71.2	0.4	0.3	27.3	0.9	28.2
1700	35.9	0.2	0.4	59.4	4.1	63.5
1800	0	0	0.5	88.3	11.2	99.5



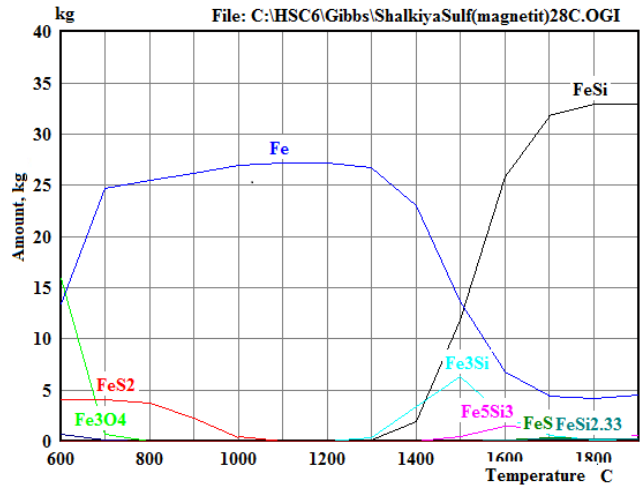
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(b)

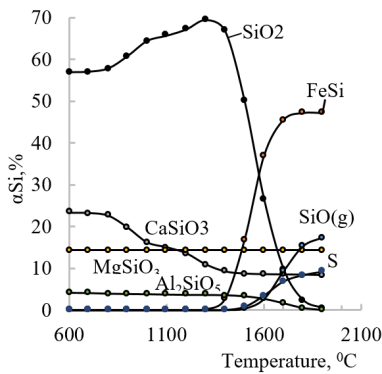


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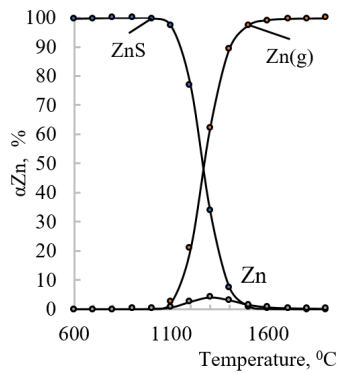


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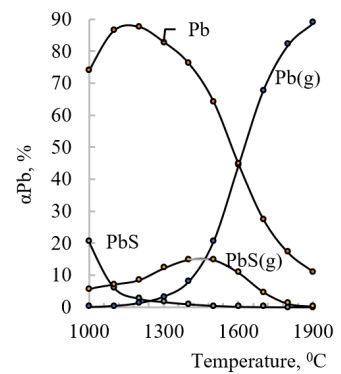
**Fig. 4** Effect of temperature on the quantitative distribution of (a) zinc, (b) lead, (c) silicon and (d) iron in the Shalkiya sulfide ore – Fe<sub>3</sub>O<sub>4</sub> – C system



(a)



(b)



(c)

**Fig. 5** Effect of temperature on the distribution degree of (a) silicon, (b) zinc and (c) lead in the sulfide ore – Fe<sub>3</sub>O<sub>4</sub> – C system

magnesium silicates. The transition of silicon into gaseous  $\text{SiO}_g$  becomes noticeable at temperatures above 1700 °C; for instance, 16.6% of silicon is lost at 1800 °C. In addition to these substances, silicon to a small extent passes into iron silicides ( $\text{FeSi}$ ,  $\text{Fe}_3\text{Si}$ ,  $\text{Fe}_5\text{Si}_3$ ,  $\text{FeSi}_2$ ,  $\text{FeSi}_{2.33}$ ) and sodium and potassium silicates; for example, at 1800 °C, 3.11% of Si is lost with these compounds (including 2% of iron silicides). The transition degree of silicon into the alloy in the form of  $\Sigma$  (iron silicides and silicon) is shown in Table 5.

It can be seen that to achieve  $\alpha\text{Si}(\text{alloy})$  over 55%, the temperature should be 1700–1900 °C. The incomplete transition of Si into the alloy is associated with the formation of calcium, aluminium, and magnesium silicates and  $\text{SiO}_g$ .

Judging by Fig. 5, zinc sulfide begins to be reduced at 1000 °C forming gaseous zinc. The formation degree of gaseous zinc at the temperature of 1500 °C is 97.5%, and at 1600 °C is 99.3%. At 1100 °C, lead was reduced from  $\text{PbS}$  by 86.76%. The extraction of lead from the ore into gas occurs due to the transition of elemental lead and its sulfide to this phase. To achieve the high (>80%) extraction degree of lead into gas in the form of  $\Sigma(\text{Pb}_g$  and  $\text{PbS}_g)$ , the temperature should be more than 1760 °C (Table 6).

#### 4 Discussion

Based on the described material, it can be seen that the comprehensive processing of Shalkiya sulfide ore is possible at the temperature of at least 1700–1900 °C. In this temperature range, the zinc and lead extraction degrees into the gaseous state are 67–91.86% and 72.48–88.32%, respectively; the transition degree of iron into the alloy is >99.8%, and silicon is 55.06–57.96%. In the temperature range of 1700–1900 °C, ferrosilicon is formed; its composition is shown in Table 7.

Electric smelting of the sulfide ore with the magnetite concentrate and coke was accompanied by intense foaming and outflow of the melt from the crucible. The cause

**Table 5** Effect of temperature on the equilibrium transition degree of silicon into the alloy

$T, ^\circ\text{C}$	1300	1400	1500	1600	1700	1800	1900
$\alpha\text{Si}(\text{alloy})$	0.5	4.8	22.0	43.9	55.1	57.6	58.0

**Table 6** Effect of temperature on the transition degree of lead from the ore into the gas phase, %

Substance	Temperature, °C				
	1600	1700	1760	1800	1900
$\text{PbS}_g$	10.8	4.8	3.7	1.03	0.2
$\text{Pb}_g$	44.2	67.7	76.3	82.0	88.2
$\Sigma(\text{PbS}_g + \text{Pb}_g)$	55.1	72.5	80.2	83.0	88.3

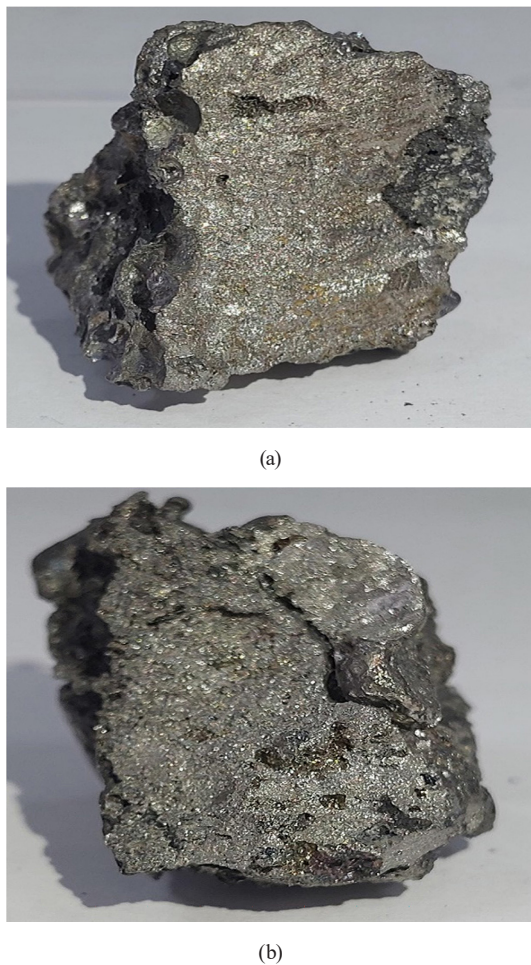
**Table 7** The ferroalloy composition, at.%

Temperature, °C	Content, %			
	Si	Fe	Pb	Zn
1700	32.0	67.4	0.6	0.03
1800	33.0	66.6	0.4	0.02
1900	33.2	66.6	0.2	0.01

of the foaming is the intense saturation of the melt with gases [30, 31]. In our case, the gaseous products were  $\text{Zn}_g$ ,  $\text{Pb}_g$ ,  $\text{CO}$ ,  $\text{SO}_2$  as well as gaseous  $\text{ZnS}$ ,  $\text{PbS}$ . The foaming is undesirable for electrothermal processes, since foam, being a highly mobile system, quickly rises to the furnace's upper horizons and fills the furnace space. Rising to the arch, the foam cools, forming a solid mass; its removal requires stopping the furnace. In our case, the foam, entraining the charge, spilled out of the crucible, disrupting the melting process. This phenomenon violates the necessary ratio of the components, leading to deterioration in the technological indicators (silicon extraction degree and silicon content in the ferroalloy). It is possible to reduce the intensity of foaming and change from the intensive foaming mode to the inactive (undeveloped) one by reducing the amount of gaseous products by means of replacing magnetite with iron in the form of steel shavings. For this purpose, we carried out experiments with two charge compositions with partial replacement of magnetite with steel shavings. The first charge composition included: ore – 1.5 kg, coke – 0.56 kg, magnetite concentrate – 0.29 kg, steel shavings – 0.3 kg. The second charge composition contained: ore – 1.5 kg, coke – 0.48 kg, magnetite concentrate – 0.12 kg, steel shavings – 0.3 kg. The share of replacing magnetite's iron with steel shavings' iron was 50% for the 1<sup>st</sup> composition and 70% for the 2<sup>nd</sup> one.

There is a method for stabilizing foam and emulsion using solid particles (Pickering emulsion) [32, 33]. However, these sources lack information on the stabilization of foams in the presence of metals. Based on the published information on the foam stabilization, one can only assume that the role of the stabilizer is to form a dense interfacial layer on the droplet (or bubble) surface, which prevents the droplets or bubbles from their coalescence. To determine the possibility of stabilizing molten foam with iron, it is necessary to perform a number of studies. Such the study was not within the scope of this work.

Samples of the resulting ferroalloys are shown in Fig. 6. The density of the ferrosilicon obtained from the 1<sup>st</sup> charge was 5.29 g/cm<sup>3</sup>, and from the 2<sup>nd</sup> one was 5.05 g/cm<sup>3</sup>.



**Fig. 6** Photograph of ferroalloys smelted from the Shalkiya sulfide ore, (a) 1<sup>st</sup> composition, (b) 2<sup>nd</sup> composition

The silicon content in the alloys, in accordance with [34], was calculated using Eq. (12):

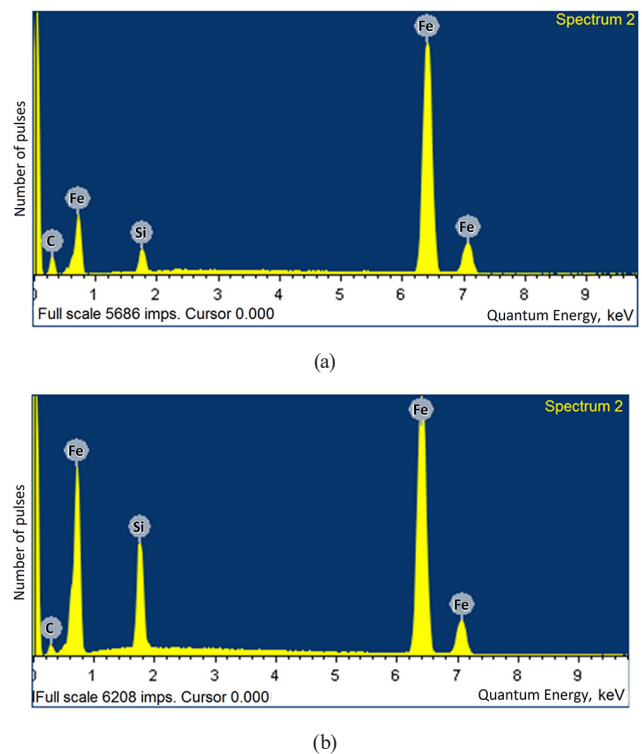
$$C_{\text{Si(ally)}} = 252.405 - 101.848D + 18.209D^2 - 1.243D^3, \quad (12)$$

where  $D$  is the density of ferrosilicon.

The silicon concentration in the alloy, produced from the 1<sup>st</sup> charge composition, was 39.10%, and from the 2<sup>nd</sup> charge composition, was 42.10%.

Results of the SEM analyzes of the resulting alloys are shown in Fig. 7 and Table 8. It can be seen that the ferroalloys contain 41.42–43.31% of silicon. In accordance with [35], these ferroalloys in terms of silicon content refer to FS45 grade ferrosilicon.

Comparison of the technological indicators, obtained at the thermodynamic modeling and experimental smelting of the Shalkiya ore, shows that the extraction degree of silicon into the alloy produced at the electric smelting is higher than at the modeling (84–88 and 57–59%, respectively). The similar situation is also observed for the silicon concentration in the alloy. At the electric smelting, it is 39.1–43.3%, and at the thermodynamic modeling, it is 31.9–33.2%.



**Fig. 7** X-ray spectra of ferroalloy samples, obtained on SEM with EDS system, smelted (a) from the 1<sup>st</sup> charge composition, (b) from the 2<sup>nd</sup> charge composition

**Table 8** Contents of elements by spectra according to Fig. 7 (element content in at.%)

	C	Si	Fe
Fig. 7 (a)	1.1	43.31	55.59
Fig. 7 (b)	1.21	41.42	57.37

This is due to the fact that during the electric smelting the solid charge, which is located in the upper horizons of the furnace (on the furnace top), retains the gaseous products of the smelting ( $\text{SiO}_g$ ,  $\text{Si}_g$ ). This reduces the silicon loss and increases the silicon transition into the alloy. Thermodynamic modeling does not allow taking into account the filtering charge layer. Therefore, the silicon loss with the gases is higher.

The sublimes, sampled from the surface of the electric holder, contained 24.45% of zinc and 10.42% of lead. In comparison with the ore, the content of zinc in the sublimes increased by 7 times and the content of lead increased by 11.9 times. It should be noted that the lead and zinc extraction degrees into the sublimes were 97.3% and 99.2%, respectively.

The developed method for processing sulfide zinc ores allows increasing the level of raw materials' comprehensive use due to the extraction of not only zinc and lead, but also silicon into the products.

Based on the results obtained, it is necessary to expand the types of sulfide raw materials that can be processed together with magnetite, for example, siliceous tailings formed at the concentration of Pb – Zn ores.

## 5 Conclusion

Based on the results obtained at the thermodynamic study and the Shalkiya ore electric smelting in the presence of magnetite and coke, the following conclusions can be drawn:

1. In the equilibrium conditions:
  - in the presence of  $\text{Fe}_3\text{O}_4$  and carbon, the reduction and formation of gaseous zinc from ZnS, according to  $\Delta G^\circ = 0$ , occurs at the temperature of 1205.7 °C;
  - when the Shalkiya sulfide ore interacts with magnetite and carbon, the formation of a ferroalloy begins at the temperature of 1200 °C; about 58% of silicon is extracted into the ferroalloy

at 1800–1900 °C, while zinc sulfide is reduced and goes into a gaseous state by 100%, and lead is reduced and goes into a gaseous state by 84–88%.

2. Electric smelting the sulfide ore in the presence of magnetite concentrate and coke makes it possible to obtain FS45 grade ferrosilicon (42–43% of Si), achieve the silicon transition degree of at least 85% and extract 97.3% of lead and 99.2% of zinc into the sublimates.
3. The suggested method of processing sulfide zinc ores allows increasing the level of the comprehensive use of the raw materials due to the extraction of not only zinc and lead, but also silicon into the products.
4. The results obtained are the basis for expanding the use of magnetite in the processing of other sulfide silica-containing raw materials, for example, Zn – Pb ores' concentration tailings.

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