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Ferroalloy production from ferrosilicon manganese dusts

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ABSTRACT

The article presents the results of studies on the influence of time, the amount of steel shavings and coke on the electric melting of ferrosilicon manganese dusts to obtain a ferroalloy. The research was carried out by the method of rotational planning of the second order (Box-Hunter plans) and by electric smelting of dust in laboratory ore-thermal arc furnace. Dust from the production of ferromanganese by LLP Taraz Metallurgical Plant, coke and steel shavings were used during the research. It was determined that to achieve $\alpha Si \geq 70\%$the process must be carried out in the presence of 25% coke and 8.1-9% steel shavings from the mass of dust for 55.8-60 minutes, to achieve αMn in an alloy of 80-85% the process must be carried out in the presence of 25% coke, 5.7-9.0% steel shavings for 41.2-54.4 minutes. When melting the charge containing 75.2% of dust, 18.8% of coke, 6% of steel shavings, within 60 minutes the weight of the ferroalloy was 258 g (38.8% of the weight of the charge or 51.6% of the weight of dust). The degree of extraction of manganese into the alloy was 82.3%, silicon - 66.1%. The resulting ferroalloy belongs to ferrosilicon manganese of the FeMnSi12 grade.

Keywords: dust, ferrosilicon manganese, steel shavings, coke, electric smelting.

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Introduction

Ferrosilicon manganese is an iron alloy based on manganese (at least 60%) and silicon (from 10 to 35%) used for deoxidation and alloying of steel, alloys, cast iron, and the production of refined manganese alloys [1]. In most countries, ferrosilicon manganese is still smelted in blast furnaces [2]. The essence of this process is the melting of manganese ores or their concentrates and iron-containing components to produce ferrosilicon-manganese and refractory slags [3]. Another share of ferrosilicon manganese smelting is accounted for ore-thermal furnaces [4-8]. The main manganese-containing raw materials are manganese ores and concentrates, quartzite is used as a silica-containing component, and iron-containing components are metal additives, pellets, iron chips, etc. [1, 9].

In 2020, Kazakhstan produced 122797 tons of ferrosilicon manganese, which was obtained in the Zhambyl region, Karaganda, Pavlodar and the city of Shymkent [10]. Half of the ferrosilicon manganese produced goes to the Russian market (28% of the ferrosilicon manganese imported by Russia comes from Kazakhstan alloy) [11].

An unavoidable waste in the production of ferrosilicon manganese is dust formed as a result of evaporation and sublimation of the main elements and their volatile compounds, as well as due to mechanical entrainment of the charge components [12-14]. For the purpose of processing and utilization of ferrosilicon manganese dusts, they are usually included in the composition of the charge for reuse in the technological process [15], and hydrometallurgical processing is also proposed [16]. The results of thermodynamic studies and exploratory experiments on dust processing by «Taraz Metallurgical Plant» LLP were published earlier [17, 18]. The article presents the results of research on the effect of time, the amount of steel chips and coke on the electric melting of ferrosilicon manganese dusts to produce a ferroalloy.

Experimental part

The studies were carried out by the method of rotatable planning of the second order (Box-Hunter plans) and electric melting of dust in a laboratory ore-thermal arc furnace.

Electric melting of the charge was carried out in a single-electrode arc furnace lined with chromomagnesite bricks. The hearth electrode was made of a graphite block. A graphite crucible (d=6cm, h=12cm) was placed on the plate. The space between the crucible and the lining was filled with graphite chips. The furnace in the upper part was closed with a removable lid with holes for the graphite electrode (d = 3 cm) and the gas outlet. Before melting, the crucible was heated with an arc for 20-25 minutes at a current of 250-300A and a voltage of 45-55V. After that, the first batch of charge (200 – 230g) was loaded into the crucible. It was melted for 3-5 minutes, then the remaining part of the charge (200 – 250g) was loaded and melted for the required time. During the melting period, the current was 350-450A, the voltage was 25-30V. The electric power was supplied to the furnace from the transformer TDZhF-1002. The required power was maintained by a thyristor regulator. The current was monitored with a Tangen 42L6 ammeter (accuracy class 1.5), and the voltage was monitored with a Chint 42L6 voltmeter (accuracy class 1.5). After electric melting, the furnace was cooled for 6 hours. The graphite crucible was removed from the furnace and broken. The ferroalloy was weighed and analyzed using scanning electron microscopy and atomic adsorption method on the AAS-1 device (Germany) for silicon, manganese, and iron.

Before melting, the dust was pelletized with a 5% solution of bentonite clay. Drying of "wet" pellets was carried out at 250 ^{0}C for 30 minutes. From Table 1, it can be seen that from a height of 0.5 m, the pellet does not collapse with 11 drops, 7 times-from a height of 1m, 2 times - from a height of 2m.

Table 1 - Dynamic strength of granules

Drop height, m	0,5	1,0	1,5	2,0	2,5
Number of non-destructive drops	11,0	7,0	3,0	2,0	1

During the research, dust from the production of ferromanganese of «Taraz Metallurgical Plant» LLP was used with the content: 53,3% MnO, 24,0% SiO_2, 5,4% MgO, 9,6% CaO, 3,8% Al_2O_3, 1,5% Fe_2O_3, 1,8% ZnO, 0,6% PbO, as well as coke (85,7%C, 5.2%SiO_2, 2.1%Fe_2O_3, 2.0%Al_2O_3, 1.6%CaO, 0.4%MgO, 0.8%H_2O, 5.0%FeO) and steel chips containing 2,1%C, 0,4%S, 97.1%Fe, 0.4% others.

Discussion of results

Figure 1 shows the effect of the time of electric melting of dusts together with 25% of coke and 7% of steel chips (from the mass of dust) on the degree of extraction of manganese and silicon into the alloy.

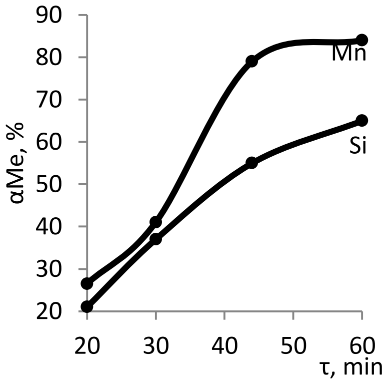
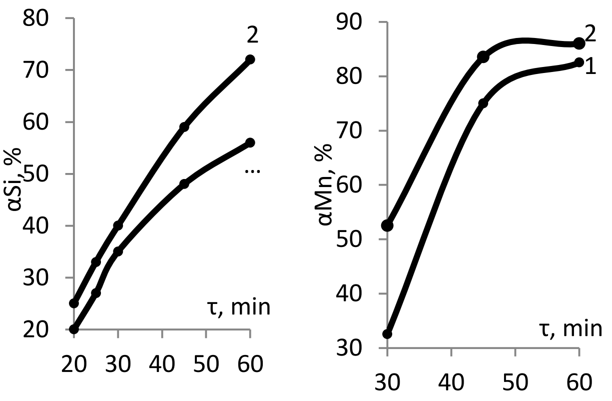


Figure 1 - Effect of time on the degree of extraction of Mn and Si in the alloy

It can be seen that, regardless of the time αMn>αSi. In 60 minutes, the degree of transition of silicon to the alloy was 64,0%, and αMn-84,2%.

Figure 2 provides information on the effect of the melting time and the amount of steel chips on the αMnandαSi, which shows that the αMn and especially theαSiare greatly influenced by the amount of steel chips. At 60 minutes of melting, an increase of 3 to 9% of the steel chips increases theαMnfrom 82,4 to 86,0%, and theαSi -from 56,0 to 72,0%.



1-3% steel shavings 2-9% steel shavings

Figure 2 - Effect of the melting time and the amount of steel chips on the degree of Si and Mn recovery in the alloy

To determine the optimal time of electric melting, the amount of steel chips at αMnand αSithe studies were carried out by the method of rotatable planning of experiments (Box-Hunter plan), followed by the construction of three-dimensional and planar images [19]. Table 2 shows the planning matrix and the experimental results of the influence of steel chips (Ch., %, by weight of dust) and coke (Coke, %, by weight of dust) on the degree of extraction of Mn and Si in the alloy.

Table 2 - Planning matrix and results of electric melting of ferrosilicon manganese dust on the effect of steel chips and coke on the degree of extraction of manganese and silicon in the alloy

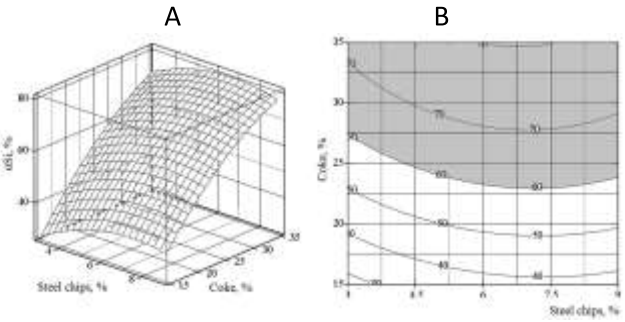
№	Variables				α_{Si}, %	α_{Mn}, %
	Encoded view		*Natural look*			
	X1	*X2*	*Ch, %*	*Coke, %*		
1	-1	-1	3,9	17,9	42.6	60.7
2	1	-1	8,1	17,9	50.6	74
3	-1	1	3,9	32,1	71.7	86.3
4	1	1	8,1	32,1	77.7	94.1
5	1.41	0	9	25	59.3	91
6	-1.41	0	3	25	54.4	76.3
7	0	1.41	6	35	79.8	93
8	0	-1.41	6	15	33.3	59.4
9	0	0	6	25	66	83
10	0	0	6	25	64.7	83.8
11	0	0	6	25	64.1	84
12	0	0	6	25	62.8	84.6
13	0	0	6	25	62	84.9

Based on the data in the table, the regression equations αSi=f (Ch, Coke) and αMn= f (Ch, Coke):

$$\alpha Si=-56{,}477+9{,}015\cdot Ch+5{,}022\cdot Coke-5{,}776\cdot 10^{-1}\cdot Ch^2-5{,}535\cdot 10^{-2}\cdot Coke^2-3{,}353\cdot 10^{-2}\cdot Ch\cdot Coke \quad (1)$$

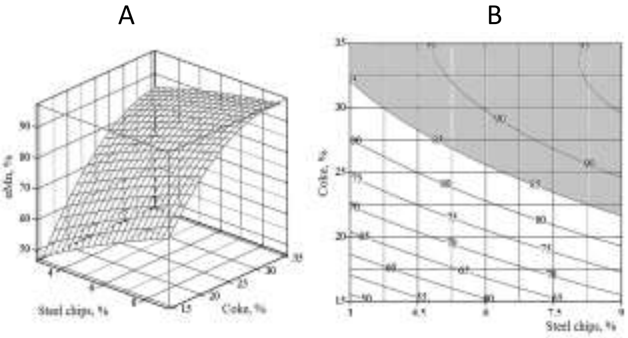
$$\alpha Mn=42{,}07+6{,}139\cdot Ch+6{,}377\cdot Coke-1{,}111\cdot 10^{-1}\cdot Ch^2-8{,}376\cdot 10^{-2}\cdot Coke^2-9{,}222\cdot 10^{-2}\cdot Ch\cdot Coke \quad (2)$$

On the basis of relations (1) and (2) according to [20], volumetric and planar images of the dependences αSi=f (Ch, Coke) and αMn= f (Ch, Coke) are constructed (Figure 3, 4).



A- volumetric images, B- planar images
Numbers on the lines- αSi, %

Figure 3 - Influence of steel chips and coke on the degree of silicon recovery in the alloy



A- volumetric images, B- planar images
Numbers on the lines- αMn, %

Figure 4 - Effect of steel chips and coke on the degree of manganese recovery in the alloy

Figure 3 shows that within 60 min αSi from 60 to 80,3% (shaded area) 3-9% of steel shavings and 22.7-35% of coke from the mass of dust are noted. Manganese is reduced better thansilicon (Fig. 4). αMn 85-93.1% (shaded area) is possible with 3-9% steel shavings and 21.6-35% by weight of dust. Table 3 shows the experiment planning matrix and their results on the effect of time (τ, min) and steel chips (Ch, % of the dust mass) on the degree of extraction of manganese and silicon into the ferroalloy. This series of experiments was conducted in the presence of 25% coke.

Table 3 - Planning matrix and results of electric melting of ferrosilicon manganese dust on the effect of steel chips and time on the degree of extraction of manganese and silicon into thealloy

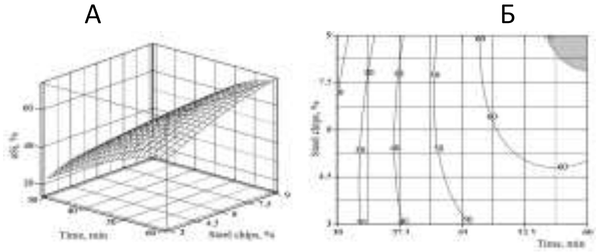
№	Variables				α_{Si}, %	α_{Mn}, %
	Encoded view		***Natural look***			
	X1	***X2***	***τ, min***	***Ch, %***		
1	-1	-1	34	3,9	32.5	56.8
2	1	-1	56	3,9	56.4	82.5
3	-1	1	34	8,1	27.7	66.7
4	1	1	56	8,1	67.2	85.0
5	1.41	0	60	6	64.8	84.2
6	-1.41	0	30	6	21.7	41.6
7	0	1.41	45	9	59.0	83.3
8	0	-1.41	45	3	49.3	75.0
9	0	0	45	6	54.0	79.0
10	0	0	45	6	54.9	81.9
11	0	0	45	6	55.4	79.5
12	0	0	45	6	55.2	81.4
13	0	0	45	6	56.0	82.0

Using the data in Table 3, the regression equations αSi=f (Ch, τ) andαMn= f (Ch, τ):

$$\alpha Si=-90{,}063+5{,}32\cdot\tau-3{,}26\cdot Ch-5{,}463\cdot10^{-2}\cdot\tau^{2}-2{,}64\cdot10^{-1}\cdot Ch+1{,}68\cdot10^{-1}\cdot\tau\cdot Ch; \tag{3}$$

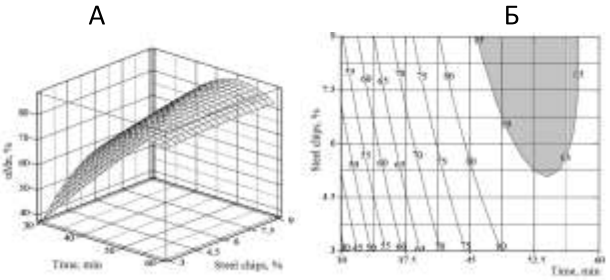
$$\alpha Mn=-148{,}039+7{,}986\cdot\tau+6{,}05\cdot Ch-7{,}023\cdot10^{-2}\cdot\tau^{2}-8{,}48\cdot10^{-2}\cdot Ch^{2}-8{,}008\cdot10^{-2}\cdot\tau\cdot Ch. \tag{4}$$

Based on equations 3 and 4, volumetric and horizontal images of the dependence [20] αSi=f (Ch, τ) and αMn= f (Ch, τ) are constructed (Figure 5, 6).



A- volumetricimages, B- planar images
Numbers on the lines- αSi, %

Figure 5-Effect of steel chips and time on the degree of silicon recovery in the alloy



A- volumetricimages, B- planar images
Numbers on the lines- αMn, %

Figure 6-Effect of steel chips and time on the degree of manganese recovery in the alloy

Figure 5 shows the effect of the melting time and the amount of steel chips on the αSiin the alloy. It can be seen that in order to achieve αSi≥70% the process in the presence of 25% coke must be carried out for 55.8-60 minutes in the presence of 8.1-9% steel chips, and in order to achieve αMnin the alloy of 80-85% (Figure 6 (shaded area), the process must be carried out in the presence of 25% coke, 5.7-9.0% steel chips from the dust mass for 41.2-54.4 minutes.

The mass of the ferroalloy obtained by melting 665g of the charge for 60 minutes (Figure 7, Table 4), containing 500g of dust, 125g of coke, 40g of steel chips, was 258g (38.8% of the charge weight or 51.6% of the dust weight). The degree of extraction of manganese in the alloy was 82.3%, silicon 66.1%. The ferroalloy contained 65%Mn, 14,9%Si, 3,6%C, 14,1%Fe and 1,3% others. According to [21], the resulting ferroalloy belongs to ferrosilicon manganese of the FeMnSi12 brand.

Figure 7 - Photo of a ferroalloy sample

Table 4 - Elemental composition of a ferroalloy sample obtained by a scanning electron microscope

Element	C	F	Na	Mg	Al	Si	S
Weight class, %	2.79	1.3	0.56	0.74	1.25	14.50	0.80
Element	K	Ca	Ti	Cr	Mn	Fe	
Weight class, %	1.21	0.69	0.26	1.27	61.06	13.57	

Conclusions

Based on the results obtained on the study of the influence of the time of electric melting, the amount of steel chips and coke on the electric melting of dusts produced by ferrosilicon manganese, the following conclusions can be drawn:

- to achieve αSi≥70% the process must be carried out in the presence of 25% coke and 8.1-9% steel chips from the dust mass for 55.8-60 minutes, and to achieve an αMn of 80-85% alloy, the process must be carried out in the presence of 25% coke, 5.7-9.0% steel chips for 41.2-54.4 minutes.

- when melting a charge containing 75.2% of dust, 18.8% of coke, 6% of steel chips, for 60 minutes, the mass of the ferroalloy was 258 g (38.8% of the mass of the charge or 51.6% of the mass of dust). The degree of extraction of manganese in the alloy was 82.3%, silicon 66.1%. The resulting ferroalloy belongs to the ferrosilicon manganese of the FeMnSi12 brand.

Conflict of interest. On behalf of all the authors, the correspondent author declares that there is no conflict of interest.

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Ферросиликомарганец өндірісінің шаңдарынан ферроқорытпа алу

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ТҮЙІНДЕМЕ

Мақалада ферроқорытпа алынатын ферросиликомарганецті шаңдардың электр балқымасына уақыттың, болат жоңқалары мен кокс мөлшерінің әсері бойынша зерттеулердің нәтижелері келтірілген. Зерттеулер екінші ретті рототабельді жоспарлау әдісімен (Бокс-Хантер жоспарлары) және зертханалық кен-термиялық доғалы пеште шаңды электрлі балқыту арқылы жүргізілді. Зерттеулерді жүргізу барысында «Тараз металлургиялық зауыты» ЖШС-нің ферромарганец өндірісіндегі шаң, кокс және болат жоңқалары қолданылды. Үрдісті жүргізгенде $\alpha Si \geq 70\%$ жету үшін шаң массасының 25,8% кокс және 8,1-9% болат үгінділерінен тұратын мөлшері 55,8-60 минут ішінде балқытылатыны, ал αMn қорытпасы 80-85%-ға жету үшін үрдісті 25% кокс, 5,7-9,0% болат жоңқалар қатысуымен 41,2-54,4 минут ішінде жүргізу керек екендігі анықталды. Құрамында 75,2% шаң, 18,8% кокс, 6% болат жоңқасы бар шихтаны 60 минут ішінде балқытқан кезде ферроқорытпаның салмағы 258 г-ды құрады (шихтаның салмағынан 38,8% немесе шаңның салмағынан 51,6%). Марганецтің қорытпаға өту дәрежесі 82,3%, кремнийдің - 66,1% болды. Алынған ферроқорытпа FeMnSi12 маркалы ферросиликомарганецке жатады.

Түйін сөздер: шаң, ферросиликомарганец, болат жоңқалар, кокс, электрлі балқыту.

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Получение ферросплава из пылей производства ферросиликомарганца

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АННОТАЦИЯ

В статье приводятся результаты исследований по влиянию времени, количества стальной стружки и кокса на электроплавку пылей ферросиликомарганца с получением ферросплава. Исследования проводили методом рототабельного планирования второго порядка (планы Бокса-Хантера) и электроплавкой пылей в лабораторной руднотермической дуговой печи. При проведении исследований использовали пыль производства ферромарганца ТОО «Таразский металлургический завод», кокс и стальную стружку. Установлено, что для достижения $\alpha Si \geq 70\%$ процесс необходимо проводить в присутствии 25% кокса и 8,1 - 9% стальной стружки от массы пыли в течение 55,8-60 минут, а для достижения αMn в сплав 80 - 85% процесс необходимо проводить в присутствии 25% кокса, 5,7 - 9,0% стальной стружки в течение 41,2 - 54,4 мин. При плавке шихты, содержащей 75,2% пыли, 18,8% кокса, 6% стальной стружки, в течение 60 мин масса ферросплава составила 258г (38,8% от массы шихты или 51,6% от массы пыли). Степень извлечения марганца в сплав составила 82,3%, кремния 66,1%. Полученный ферросплав относится к ферросиликомарганцу марки FeMnSi12.

Ключевые слова: пыль, ферросиликомарганец, стальная стружка, кокс, электроплавка.

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Литература

[1] Гасик М.И. Лякишев Н.П. Теория и технология электрометаллургии ферросплавов. - М.: СП Интермет Инжиниринг, 1999. – 764с.
[2] Доменное производство ферромарганца, ферросилиция и феррохрома. Metalspace. [Электрон. ресурс]-2021. - URL:https://metalspace.ru/en/history-metallurgy/tom3/iron-alloys/1147-domennoe-proizvodstvo-ferromargantsa-ferrosilitsiya-i-ferrokhroma.html (дата обращения: 15.05.2021)
[3] Пат. 2 134 299 РФ. Способ выплавки ферромарганца в доменных печах / Рубин З.Е., Некрасов Г.Е., Брусенко С.В., Шепилов С.В., Титов В.И., Хайдуков В.П., Бабаев Э.Д., Бабаев М.Д., Ярошевский С.Л., Бродский М.Л. Опубл. 10.08.1999.
[4] Пат. 2190683 РФ. Способ выплавки ферросиликомарганца / Мизин В.Г., Зарапин А.Ю., Перекатов С.В., Захаров Д.В., Харлан В.В., Хайбуллин В.Г. Опубл. 10.10.2002.
[5] Рысс М.А. Производство ферросплавов. -М.: Металлургия,1985. -344 с.
[6] Пат. SU1636469A2. Способ получения ферросиликомарганца/ Столяр О.Ю., Мельниченко А. А., Филиппов И. Ю., Иванова В. П., Иванишко В. С. Опубл. 23.03.1991. Бюл. №11
[7] Ферросиликомарганец (МнС17). ЗАО «Камышинский литейно-ферросплавный завод». [Электрон. ресурс]-2021. - URL: https://www.zaoklfz.ru/docs/ferrosilikomarganets.html (дата обращения: 10.05.2021)
[8] Пат. RU93020147A РФ. Способ получения ферросиликомарганца // Гладышев Н.Г., Колганов Г.С., Лезник И.Д., Кошелев С.П., Исхаков А.Ф., Вайнштейн Ш.И., Воронин Б.В., Кретинин А.С., Кошелев И.С., Зверев В.А., Тарасов Е.Н., Хмелевской А.Б. Опубл. 20.04.1993.

[9] Сариев О. Р., Досекенов М. С., Келаманов Б. С., Абдирашит А. М. Выплавка высокоуглеродистого ферромарганца на высокоосновных шлаках // Комплексное использование минерального сырья. -2020. -№4(315). -С.63-73. https://doi.org/10.31643/2020/6445.38

[10] Бюро национальной статистики Агентства по стратегическому планированию и реформам Республики Казахстан. [Электрон. ресурс]-2021. -URL: https://stat.gov.kz/(дата обращения: 13.05.2021)

[11] Рынок силикомарганца в 2020 году и 1 квартале 2021 года. Информационное агентство MetalTorg.Ru. [Электрон. ресурс] -2021. -URL: https://www.metaltorg.ru/analytics/ores/?id=789 (дата обращения: 13.05.2021)

[12] Кожамуратов Р.У., Сафаров Р.З., Шоманова Ж.К., Носенко Ю.Г. Утилизация отходов ферросплавного производства // Global Science and Innovations 2017: матер. междунар. конф. -Bursa, Turkey, 2017. -С. 207-213.

[13] Казюта В. И. Утилизация пыли металлургических производств и отработанных фильтровальных материалов // Сталь. -2014. -№9. -С. 95-102

[14] Stalinsky D.V., Petrov Y.L. Innovative approaches when creating modern environmentally safe and energy efficient ferroalloy productions // Energy efficiency and environmental friendliness are the future of the global Ferroalloy industry: Proceedings of the Fourteenth International Ferroalloys Congress INFACON XIV. -Kiev, Ukraine, 2015. – T. 2. – P. 733–737.

[15] Равич Б. М., Окладников В. П., Лыгач В. Н., Менковский М. А. Комплексное использование сырья и отходов. -М.: Химия, 1988. -288 с.

[16] Исабаев С.М., Кузгибекова Х.М., Жинова Е.В., Жилина И.М., Жамухаметова А.Т. Гидрометаллургическая переработка некондиционного марганецсодержащего сырья с получением высококачественных продуктов// Комплексное использование минерального сырья. -2018. -№. 4. -С.166-172. https://doi.org/10.31643/2018/6445.43

[17] Shevko V.M., Sinelnikov I.P., Karataeva G.E., Badikova A.D. Electrothermal re-processing of dust produced during ferromanganese production // Vestnik Irkutskogo gosudarstvennogo tehnicheskogo universiteta = Proceedings of Irkutsk State Technical University. -2020. -24(4). -P.931–944. https://doi.org/10.21285/1814-3520-2020-4-931-944

[18] Синельников И. П., Шевко В. М., Каратаева Г. Е. Получение ферросплава из пылей производства ферросиликомарганца// Повышение качества образования, современные инновации в науке и производстве: матер. междунар. научн. -практ. конф. -Экибастуз-Прокопьевск, Казахстан. -2020. -С. 63-67

[19] Ахназарова С.Л., Кафаро Volume 3, Issue 318, 2021 в В.В. Методы оптимизации эксперимента в химической промышленности. -М.: Высшая школа, 1985. -327 с.

[20] Очков В.Ф. Mathcad 14 для студентов, инженеров и конструкторов. -СПб: БХВ-Петербург, 2009. -512 с

[21] ГОСТ 4756-91. Ферросиликомарганец. Технические требования и условия поставки. -М.: Стандартинформ, 2011. -7с.

Reference

[1] Gasik M.I., Lyakishev N.P. *Teoriya i tekhnologiya elektrometallurgii ferrosplavov* (Theory and technology of electrometallurgy of ferroalloys). Moscow: SP Intermet Engineering, 1999, 764. (in Russ.).

[2] Blast-furnace production of ferromanganese, ferrosilicon and ferrochrome. Metalspace. URL:https://metalspace.ru/en/history-metallurgy/tom3/iron-alloys/1147-domennoe-proizvodstvo-ferromargantsa-ferrosilitsiya-i-ferrokhroma.html (date of access: 15.05.2021)

[3] Pat. 2 134 299 RU. *Sposob vyplavki ferromargantsa v domennykh pechakh* (Method for smelting ferromanganese in blast furnaces) / Rubin Z.E., Nekrasov G.E., Brusenko S.V., Shepilov S.V., Titov V.I., Khaydukov V.P., Babayev E.D., Babayev M.D., Yaroshevskiy S.L., Brodskiy M.L. Opubl. 10.08.1999. (in Russ.).

[4] Pat. 2190683 RU. *Sposob vyplavki ferrosilikomargantsa* (Method of ferrosilicon manganese smelting)/ Mizin V.G., Zarapin A.Yu., Perekatov S.V., Zakharov D.V., Kharlan V.V., Khaybullin V.G. Opubl. 10.10.2002. (in Russ.).

[5] Ryss M.A. *Proizvodstvo ferrosplavov (*Ferroalloy production). Moscow: Metallurgy, 1985, 344 (in Russ.).

[6] Pat. SU1636469A2. *Sposob polucheniya ferrosilikomargantsa* (Method of producing ferrosilicon manganese)/ Stolyar O.Yu., Melnichenko A. A., Filippov I. Yu., Ivanova V. P., Ivanishko V. S. Opubl. 23.03.1991, №11. (in Russ.).

[7] Ferrosilicon manganese (MnC17). CJSC Kamyshinsk Foundry and Ferroalloy Plant-URL: https://www.zaoklfz.ru/docs/ferrosilikomarganets.html (date of access: 10.05.2021)

[8] Pat. RU93020147A RU. *Sposob polucheniya ferrosilikomargantsa* (Method of producing ferrosilicon manganese) // Gladyshev N.G., Kolganov G.S., Leznik I.D., Koshelev S.P., Iskhakov A.F., Vaynshteyn Sh.I., Voronin B.V., Kretinin A.S., Koshelev I.S., Zverev V.A., Tarasov E.N., Khmelevskoy A.B. Opubl. 20.04.1993. (in Russ.).

[9] Sariyev O. R., Dosekenov M. S., Kelamanov B. S., Abdirashit A. M. *Vyplavka vysokouglerodistogo ferromargantsa na vysokoosnovnykh shlakakh (*High-carbon ferromanganese smelting on high-base slags*)// Kompleksnoe Ispol'zovanie Mineral'nogo Syr'a. = Complex Use of Mineral Resources = Mineraldik Shikisattardy Keshendi Paidalanu*. 2020. *4(315)*, 63-73. https://doi.org/10.31643/2020/6445.38 (in Russ.).

[10] Agency for Strategic planning and reforms of the Republic of Kazakhstan Bureau of National statistics. URL: https://stat.gov.kz/ (date of access: 13.05.2021)

[11] Silicomanganese market in 2020 and Q1 2021. Information agency MetalTorg.Ru. URL: https://www.metaltorg.ru/analytics/ores/?id=789 (date of access: 13.05.2021)

[12] Kozhamuratov R.U., Safarov R.Z., Shomanova Zh.K., Nosenko Yu.G. *Utilizatsiya otkhodov ferrosplavnogo proizvodstva* (Utilization of ferroalloy production waste) // *Global Science and Innovations 2017: mater. mezhdunar. konf.* (Global

Science and Innovations 2017: proceedings of Internation. Conf. Bursa, Turkey, 2017. 207-213. (in Russ.).

[13] Kazyuta V. I. *Utilizatsiya pyli metallurgicheskikh proizvodstv i otrabotannykh filtrovalnykh materialov* (Utilization of metallurgical dust and used filter materials) // *Stal =Steel*. 2014. 9, 95-102 (in Russ.).

[14] Stalinsky D.V., Petrov Y.L. Innovative approaches when creating modern environmentally safe and energy efficient ferroalloy productions // Energy efficiency and environmental friendliness are the future of the global Ferroalloy industry: Proceedings of the Fourteenth International Ferroalloys Congress INFACON XIV. Kiev, Ukraine, 2015. *2,* 733–737 (in English)

[15] Ravich B. M., Okladnikov V. P., Lygach V. N., Menkovskiy M. A. *Kompleksnoye ispolzovaniye syria i otkhodov* (Integrated use of raw materials and waste). Moscow: Chemistry, 1988, 288. (in Russ.).

[16] Isabayev S.M., Kuzgibekova Kh.M.. Zhinova E.V., Zhilina I.M., Zhamukhametova A.T. *Gidrometallurgicheskaya pererabotka nekonditsionnogo marganetssoderzhashchego syria s polucheniyem vysokokachestvennykh produktov* (Hydrometallurgical processing of non-concentrated manganese - containing raw material with receiving high-quality products)// *Kompleksnoe Ispol’zovanie Mineral’nogo Syr’a. = Complex Use of Mineral Resources = Mineraldik Shikisattardy Keshendi Paidalanu*. 2018. *4*, 166-172. https://doi.org/10.31643/2018/6445.43 (in Russ.).

[17] Shevko V.M., Sinelnikov I.P., Karataeva G.E., Badikova A.D. Electrothermal re-processing of dust produced during ferromanganese production // *Vestnik Irkutskogo gosudarstvennogo tehnicheskogo universiteta = Proceedings of Irkutsk State Technical University*. 2020. *24(4)*, 931–944. https://doi.org/10.21285/1814-3520-2020-4-931-944 (in English)

[18] Sinelnikov I. P., Shevko V. M., Karatayeva G. E. *Polucheniye ferrosplava iz pyley proizvodstva ferrosilikomargantsa* (Obtaining ferroalloy from dusts of ferrosilicon manganese production) // *Povysheniye kachestva obrazovaniya. sovremennyye innovatsii v nauke i proizvodstve: mater. mezhdunar. nauchn. -prakt. konf. (Improving* the quality of education, modern innovations in science and production: proceedings of Internation. Conf.) Ekibastuz-Prokopyevsk, Kazakhstan, 2020. 63-67 (in Russ.).

[19] Akhnazarova S.L., Kafarov V.V. *Metody optimizacii eksperimenta v himicheskoj promyshlennosti* (Experiment Optimization Methods in the Chemical Industry). Moscow: High school, 1985, 327. (in Russ.).

[20] Ochkov V.F. *Mathcad 14 dlya studentov, inzhenerov i konstruktorov* (Mathcad 14 for students, engineers and designers). St. Petersburg: BHV-Petersburg, 2009, 512 (in Russ.).

[21] State standard 4756-91. *Ferrosilikomarganets. Tekhnicheskiye trebovaniya i usloviya postavki* (Ferrosilicon manganese. Technical requirements and terms of delivery). Moscow: Standartinform, 2011, 7. (in Russ.).