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Calculation of material and heat balance of melting refined ferrochrome using the new complex reducing agent of aluminosilicochrome

[1] Baisanova A.M., [2] Shabanov Ye.Zh., [3] Grigorovich K.V.

[1] Karaganda Technical University, Karaganda, Kazakhstan
[2] Abishev Chemical and metallurgical Institut, Karaganda, Kazakhstan
[3] Baikov Institute of metallurgy and materials science, Russian Academy of Sciences, Moscow, Russian Federation

** Corresponding author email: ye.shabanov@gmail.com*

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ABSTRACT
The article presents the results of calculating the material and thermal balances of refined ferrochrome (RFeCr) smelting using a new reducing agent. According to the results of the material balance and enlarged laboratory tests, it was found that when the traditional reducing agent silicochrome (FeSiCr48) is completely replaced with a complex alloy of aluminosilicochrome (FeAlSiCr), a metal of the following chemical composition can be obtained, %: Cr 66.8-69.1; C 0.21-0.29, Si 1.91-2.02. The composition of FeAlSiCr for silicon and chromium is the same as that of FeSiCr48, but additionally contains Al. In the process of obtaining refined ferrochrome, this aluminum passed into slag and changed its phase composition. In the CaO-MgO-Al_2O_3-SiO_2 system, the phase composition of the slag moved from the region of bicalcium silicate to the region of helenite, which allowed to obtain non-crumbling slags. In addition, due to the high activity of FeAlSiCr (where, $\sum = Si + Al \geq 60\%$), the basicity of the slag was maintained at the level of CaO/SiO_2 = 1.6-1.7, against to 2. Based on the results of the heat balance calculation, it was found that the use of a complex FeAlSiCr reducing agent leads to a 24% reduction in electricity consumption. The low power consumption compared to the classical technology is explained by the presence of two active elements in the FeAlSiCr, silicon and aluminum. Thus, the amount of heat introduced by exothermic reactions prevails with the heat introduced by electrical energy.

Keywords: refined ferrochrome, aluminosilicochrome , reductant, ferroalloy, material balance.

Information about authors:

Baisanova Aidana Maksutovna — *Doctoral student of Karaganda Technical University, Karaganda, Kazakhstan. ORCID ID: Email: baisanova.aidana@mail.ru*

Shabanov Yerbol Zhaksylykuly — *PhD, head of the laboratory "Ferroalloys and recovery processes", Chemical and metallurgical Institute named after Zh. Abishev, Karaganda, Kazakhstan. ORCID ID: 0000-0001-6902-1211. Email: ye.shabanov@gmail.com*

Grigorovich Konstantin Vsevolodovich — *Doctor of Engineering Sciences, head of the Center for collective use of scientific equipment "Diagnostics of materials" of the Institute of metallurgy and materials science. A. A. Baykov, RAS, Moscow, Russian Federation. Email: grigorov@imet.ac.ru.*

Introduction

The production and use of a complex aluminosilicochrome alloy is a complex scientific and technical problem associated with the development of effective technological processes for their production and the rationalization of alloy compositions. Therefore, for the development of the aluminosilicochrome alloy, a scientific base was created based on the regularities of the state diagrams of the Fe-Al-Si-Cr system, and laboratory and enlarged laboratory tests were carried out in an ore-thermal furnace with a transformer power of 200 kVA to obtain the alloy itself with its further use at smelting of refined ferrochrome (RFeCr).

Considering the disadvantages (scattering of slags, an increase in the basicity and multiplicity of the slag, as well as the consumption of specific electricity to obtain 1 ton of metal) of the current technology for smelting refined ferrochrome at the Abishev Chemical and Metallurgical Institute, work was carried out to replace the traditional reductant ferrosilicochrome with a new alloy - aluminosilicochrome. The use of aluminosilicochrome as a reducing agent instead of ferrosilicochrome is due to the sufficient content of silicon and aluminum in it. The presence of chemical compounds and solid solutions of iron, silicon and aluminum in aluminosilicochrome should significantly reduce the losses of silicon and aluminum for oxidative processes when interacting with atmospheric oxygen [1-4].

In comparison with the traditional method, the developed technology for smelting refined ferrochrome has the following advantages:

- increasing the degree of extraction of chromium into metal;
- establishing the value of the basicity of the slag and, as a result, reducing the consumption of lime and reducing the frequency of slag;
- stabilization of final slags from spillage.

At the Abishev Chemical and Metallurgical Institute research was carried out on the smelting of refined ferrochrome using a complex reductant aluminosilicochrome in a refining-type electric furnace with a transformer power of 300 kVA [5].

In general, the process of smelting RFeCr using the new reducing agent was characterized by stable electrode fit. The use of aluminosilicochrome has led to the intensification of processes in the furnace. Fluctuations in the current load were noted closer to the time the alloy was tapped from the furnace, when metal accumulated in the furnace bath. The reaction zone was characterized by a high temperature (temperature of white heat, over 1200 °C).

During the campaign, 29 heats were carried out. It has been established that when using a new complex reductant aluminosilicochrome metal and slag with the following chemical compositions are obtained, %: Cr 66,8-69,1; C 0,21-0,29, Si 1,91-2,02 (metal); Cr_2O_3 4,13-7,94; SiO_2 20,37-26,41; Al_2O_3 18,24-21,97; CaO 27,87-35,8; MgO 11,95-18,26 (slag). The resulting metal in terms of the content of the main elements corresponds to the grade composition of low-carbon ferrochrome (GOST 4757 - 91, ISO 5448 - 81). Despite the relatively high percentage of carbon (0,52 %) in the composition of the new reducing agent aluminosilicochromium, its content in the final metal (RFeCr) corresponded to the permissible limits.

The use of the FeAlSiCr alloy contributed to the stabilization of the structure of self-disintegrating slags from disintegration due to the movement of their phase region from larnite to the helenite region. The samples of the obtained slags were kept in natural conditions for several months and their resistance to spillage was visually established.

In industrial furnaces, about 5,2 MW of electricity is consumed to smelt 1 ton of low-carbon ferrochrome. Given the large heat losses and structural features of the experimental 300 kVA furnace, it is impossible to achieve this figure. Therefore, in order to issue an objective assessment of the specific power consumption, appropriate calculations were carried out.

The aim of this work is to calculate the material and heat balances of refined (low-carbon) ferrochrome smelting using a complex reductant aluminosilicochrome. The tasks of calculating the material balance are to determine the consumption of a complex reductant aluminosilicochrome and to compare the results of smelting refined ferrochrome by traditional and proposed methods. Another task of the calculations is the theoretical determination and comparison of the specific consumption of electrical energy.

Calculated part

The material balance was calculated using the method of F.P. Edneral and A.F. Filippov [6].

To carry out experimental studies on the development of a technology for smelting refined ferrochrome, chromium ore of the Donskoy GOK was used, as a fluxing material - burnt lime, in which the content of calcium oxide is 75-80 %. The chemical compositions of the charge materials are shown in tables 1-3.

Table 1 – The chemical composition of chrome ore

Chrome ore, %									
Cr_2O_3	SiO_2	CaO	MgO	Al_2O_3	FeO	Fe_2O_3	S	P	other
45,09	6,44	1,30	14,29	8,99	10,42	2	0,024	0,02	3,21

Table 2 – The chemical composition of the complex alloy FeAlSiCr

FeAlSiCr (aluminum-chrome-silicon), %					
Cr	Si	Al	C	Ca+Mg	Fe
13,9	51,07	21,66	0,51	0,5	9,97

Table 3 – The chemical composition of lime

Lime, %								
SiO_2	CaO	MgO	Al_2O_3	FeO	Fe_2O_3	S	P	other
0,23	67,77	0,01	0,01	0,0089	0,01	0,024	0,02	30,97

The charge calculation was based on the following chemical reaction equations (1-4):

$$Cr_2O_3 + 3/2Si = 2Cr + 3/2SiO_2 \quad (1)$$

$$2FeO + Si = 2Fe + SiO_2 \quad (2)$$

$$Cr_2O_3 + 2Al = 2Cr + Al_2O_3 \quad (3)$$

$$3FeO + 2Al = 3Fe + Al_2O_3 \quad (4)$$

In the course of calculating the ratio of charge materials on the basis of production and literature data, the following distribution of elements was taken (table 4).

Table 4 – Distribution of recovered items

Element	Cr	Fe	Al	Si	P
Converts,%: into metal	85	95	1	5	50
into slag	15	5	89	85	25
away	0	0	10	10	25

Table 5 – Estimated material balance of refined ferrochrome smelting at slag basicity

Basicity (CaO/SiO_2)	Set, kg		Received, kg	
1,7	chrome ore	100,00	metal	49,85
	aluminosilicochrome	26,99	slag	121,20
	lime	70,31	away	24,98
	air oxygen	3,14	discrepancy	4,41
	total	200,44	total	200,44

The results of calculations of the material balance of refined ferrochrome production using a complex reducing agent are presented in table 5.

To calculate the heat balance, we used the thermophysical characteristics of materials, the heat effects of reactions, and the results of calculating the material balance. In the incoming part of the heat balance, the physical heat of the charge, the heat of exothermic reactions, and the heat introduced by electricity were taken into account. In the consumable part, the heat content of the metal and slag, the loss of the furnace surface and with the exhaust gases.

For a comparative assessment of the results of calculating the heat balance of smelting RFeCr, table 6 presents the calculated data of the authors [7], which shows the heat balance of the production of low-carbon ferrochrome using the traditional reductant - ferrosilicochrome.

Table 6 – Heat balance of production of low-carbon ferrochrome using ferrosilicochrome

Coming, %		Expenditure, %	
Physical heat of the charge + heat of oxidation C (electrodes)	4,1	Heat content of metal	11,5
Heat of exothermic reduction reactions, slag formation, combustion of excess reduction	30,7	Slag heat content	71,4
Heat introduced by electricity	65,2	Furnace surface loss	7,5
		Waste gas losses	9,6
Total	100	Total	100

The results of calculating the heat balance of refined ferrochrome using the complex reductant aluminosilicochrome are presented in table 7. In the calculations, as a rule, the ambient temperature is taken as the zero point in temperature. The charge will add additional heat if its temperature exceeds the temperature of the medium. Since in our case, according to the calculation conditions, preliminary heating of the charge is not provided, the charge will not add additional heat.

Table 7 - Results of calculating the heat balance of refined ferrochrome using a complex reductant aluminosilicochrome

Coming			**Expenditure**		
Article	**kj**	**%**	**Article**	**kj**	**%**
Physical heat of the charge	0	0	Heat content of the alloy	77 100	7,1
Exothermic reactions	946 288	87,53	Slag heat content	677 918	62,7
Electricity	134 767	12,46	Heat content of gaseous products	4 249	0,3
			Endothermic reactions	23 727	2,1
			Heat loss	298 161	27,5
Total	1 081 055	100,0	Total	1 081 055	100,0

The discussion of the results

The low power consumption in comparison with the classical technology is explained by the presence of aluminum in the composition of aluminosilicochromium. In the heat balance it is shown that, depending on the used reducing agent, the values of the introduced heat of exothermic reactions and electricity change (tables 6-7).

Based on the results of heat balance calculations, the specific power consumption for the production of 1 ton of refined ferrochrome was determined, which is 3,9 MW/t. If we compare the production data (5,2 MW/t) with the obtained data, then the energy savings when using the new reducing agent is 25%.

Conclusions

1. Calculations of the material and heat balances of refined ferrochrome smelting when using a complex aluminum-chromium-containing alloy of aluminosilicochrome as a reducing agent have been performed. As a result of calculating the heat balance, it was found that the use of a complex reductant in the smelting of refined ferrochrome leads to a 25% decrease in power consumption.

2. According to the results of enlarged laboratory tests, it was found that with the complete replacement of the traditional reducing agent silicochromium (FeSiCr48) with a complex alloy of aluminosilicochrome (FeAlSiCr), it is possible to obtain a metal of the following chemical composition, %: Cr 66,8-69,1; C 0,21-0,29, Si 1,91-2,02.

Conflict of interest

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

Алюмосиликохромды жаңа кешенді тотықсыздандырғышты қолдана отырып, тазартылған феррохромды балқытудың материалдық және жылу балансын есептеу

[1] Байсанова А.М., [2] Шабанов Е.Ж., [3] Григорович К.В.

[1] Қарағанды Техникалық Университеті, Қарағанды, Қазақстан
[2] Ж.Әбішев атындағы Химия-металлургиялық институты, Қарағанды, Қазақстан
[3] А.А. Байков атындағы Металлургия және материалтану институты, РҒА, Мәскеу, Ресей Федерациясы

** Corresponding author email: ye.shabanov@gmail.com*

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ТҮЙІНДЕМЕ
Мақалада жаңа тотықсыздандырғышты қолдана отырып, тазартылған феррохромды (РФХ) балқытудың материалдық және жылу баланстарын есептеу нәтижелері келтірілген. Материалдық баланс және ірілендірілген-зертханалық сынақтар нәтижелері бойынша дәстүрлі тотықсыздандырғыш силикохромды (ФСХ48) алюмосиликохром (ФАСХ) кешенді қорытпасына толық ауыстыру кезінде келесі химиялық құрамдағы металды алуға болатындығы анықталды, %: Cr 66,8-69,1; C 0,21-0,29, Si 1,91-2,02. ФАСХ-тың құрамы кремний мен хром бойынша ФСХ48-мен бірдей, бірақ құрамында қосымша Al-і бар. Тазартылған феррохромды алу барысында бұл алюминий қожға өтіп, оның фазалық құрамын өзгертті. CaO-MgO-Al_2O_3-SiO_2 жүйесінде қождың фазалық құрамы екі кальцийлі силикаттан (ларнит) геленит аймағына көшті, сөйтіп үгітілмейтін кесек қождарды алуға мүмкіндік берді. Бұдан басқа, ФАСХ белсенділігінің жоғары болуына байланысты (мұнда, ∑ = Si + Al ≥ 60%) қождың негіздiлігінің бірлігін 2 емес, CaO/SiO_2 = 1,6-1,7 деңгейінде ұстап тұру мүмкін болды. Жылу балансын есептеу нәтижелері бойынша ФАСХ кешенді тотықсыздандырғышын пайдалану электр энергиясының шығынын 24%-ға азайтуға мүмкіндік берді. Классикалық технологиямен салыстырғанда электр энергиясының төмен шығыны ФАСХ-тың құрамында екі белсенді элементтің, кремний мен алюминийдің болуымен түсіндіріледі. Осылайша, экзотермиялық реакциялар арқылы енгізілетін жылу мөлшері электр энергиясымен берілген жылудан басым болады.
Түйін сөздер: тазартылған феррохром, алюмосиликохром, тотықсыздандырғыш, ферроқорытпа, материалдық баланс.

Авторлар туралы ақпарат:

Байсанова Айдана Максутовна	*Қарағанды Техникалық Универститетінің докторанты, Қарағанды, Қазақстан. ORCID ID: Email: baisanova.aidana@mail.ru*
Шабанов Ербол Жақсылықұлы	*PhD докторы, "Ферроқорытпалар және тотықсыздандыру үрдістері" зертханасының меңгерушісі, Ж.Әбішев атындағы Химия-металлургия институты, Қарағанды, Қазақстан. ORCID ID: 0000-0001-6902-1211. Email: ye.shabanov@gmail.com*
Григорович Константин Всеволодович	*Техника ғылымдарының докторы, А. А. Байков атындағы Металлургия және материалтану институтының "Материалдар диагностикасы" ғылыми жабдықтарын ұжымдық пайдалану орталығының меңгерушісі, РҒА, Мәскеу, Ресей Федерациясы. Email: grigorov@imet.ac.ru.*

Расчет материального и теплового баланса плавки рафинированного феррохрома с использованием нового комплексного восстановителя алюмосиликохрома

[1] Байсанова А.М., [2] Шабанов Е.Ж., [3] Григорович К.В.

[1] Карагандинский Технический Университет, Караганда, Казахстан
[2] Химико-металлургический институт имени Ж.Абишева, Караганда, Казахстан
[3] Институт металлургии и материаловедения им. А.А. Байкова, РАН
г. Москва, Российская Федерация

** Электронная почта автора: ye.shabanov@gmail.com*

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АННОТАЦИЯ
В статье представлены результаты расчета материального и теплового балансов выплавки рафинированного феррохрома (РФХ) с использованием нового восстановителя. По результатам материального баланса и укрупненно-лабораторных испытаний установлено, что при полной замене традиционного восстановителя силикохрома (ФСХ48) на комплексный сплав алюмосиликохром (ФАСХ) можно получить металл следующего химического состава, %: Cr 66,8-69,1; C 0,21-0,29, Si 1,91-2,02. Состав ФАСХ по кремнию и хрому такой же, как у ФСХ48, но дополнительно содержит Al. В процессе получения рафинированного феррохрома этот алюминий перешел в шлак и изменил его фазовый состав. В системе CaO-MgO-Al_2O_3-SiO_2 фазовый состав шлака переместился из области двухкальциевого силиката в область геленита, что позволил получить не рассыпающиеся шлаки. Вдобавок из-за высокой активности ФАСХ (где, ∑ = Si + Al ≥ 60%) основность шлака удалось поддерживать на уровне CaO/SiO_2 = 1,6-1,7, против к 2. По результатам расчета теплового баланса установлено, что использование комплексного восстановителя ФАСХ приводит к уменьшению расхода электроэнергии на 24%. Низкий расход электроэнергии по сравнению с классической технологией объясняется наличием в составе ФАСХ двух активних элементов, кремния и алюминия. Таким образом, количество вносимого тепла экзотермическими реакциями преобладает с теплом вносимой электрической энергией.
Ключевые слова: рафинированный феррохром, алюмосиликохром, восстановитель, ферросплав, материальный баланс.

Информация об авторах:

Байсанова Айдана Максутовна	*Докторант Карагандинского Технического Университета, Караганда, Казахстан. ORCID ID: Email: baisanova.aidana@mail.ru*
Шабанов Ербол Жақсылықұлы	*Доктор PhD, заведующий лабораторией «Ферросплавов и процессов восстановления», Химико-металлургический институт имени Ж.Абишева, Караганда, Казахстан. ORCID ID: 0000-0001-*

	6902-1211. Email: ye.shabanov@gmail.com
Григорович Константин Всеволодович	*Доктор технических наук, заведующий Центра коллективного пользования научным оборудованием «Диагностика материалов» Института металлургии и материаловедения им. А.А. Байкова, РАН, Москва, Российская Федерация. Email: grigorov@imet.ac.ru.*

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