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

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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-Al₂O₃-SiO₂ 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, $\Sigma = \text{Si} + \text{Al} \geq 60\%$), the basicity of the slag was maintained at the level of CaO/SiO₂ = 1.6-1.7, against 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.

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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 aluminosilichrome 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 aluminosilichrome 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 aluminosilichrome 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 aluminosilichrome 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); Cr₂O₃ 4,13-7,94; SiO₂ 20,37-26,41; Al₂O₃ 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 aluminosilichrome, 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 aluminosilichrome. The tasks of calculating the material balance are to determine the consumption of a complex reductant aluminosilichrome 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 ₂ O ₃	SiO ₂	CaO	MgO	Al ₂ O ₃	FeO	Fe ₂ O ₃	S	P	other
45,09	6,44	1,30	14,29	8,99	10,42	2	0,024	0,02	3,21

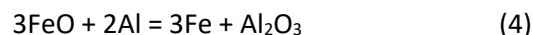
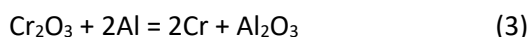
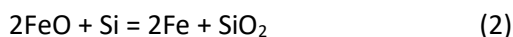
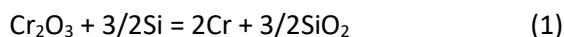
Table 2 – The chemical composition of the complex alloy FeAlSiCr

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 ₂ O ₃	FeO	Fe ₂ O 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):



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
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%.

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.

Conclusions

1. Calculations of the material and heat balances of refined ferrochrome smelting when

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

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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, %: Сг 66,8-69,1; С 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-Al₂O₃-SiO₂ 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, $\Sigma = Si + Al \geq 60\%$) қождың негізділігінің бірлігін 2 емес, CaO/SiO₂ = 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.

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

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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, %: Сг 66,8-69,1; С 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-Al₂O₃-SiO₂ фазовый состав шлака переместился из области двухкальциевого силиката в область геленита, что позволил получить не рассыпающиеся шлаки. Вдобавок из-за высокой активности ФАСХ (где, $\Sigma = Si + Al \geq 60\%$) основность шлака удалось поддерживать на уровне CaO/SiO₂ = 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 активных 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.

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<https://doi.org/10.31643/2020/6445.37>

Литература

- [1] Акуов А.М., Толымбеков М.Ж., Избембетов Д.Д. и др. Термографические исследования хромового сырья и шихт на его основе // Повышение качества образования и научных исследований: Матер. междунар. науч.-практ. конф. – Екибастуз, Казахстан, 2008. – С. 320-323.
- [2] Алмагамбетов М.С. Разработка технологии выплавки рафинированных сортов феррохрома с применением ферросиликоалюминия: дис. ... канд. техн. наук: 05.16.02. – Караганда: ХМИ, 2009. – 138 с.
- [3] Морозов А.Н., Лисняк С.С., Беликов А.М. Изменение состава и структуры хромистых руд в процессе их нагревания и восстановления // Сталь. – 1963. – №2. – С.137-139.
- [4] Беляев С.В., Кузгибекова Х.М., Каргина Н.А., Жинова Е.В. Разработка математической модели процесса извлечения хрома из хромсодержащего материала // Комплексное использование минерального сырья. – 2011. – № 6. – С. 33-40.
- [5] Shabanov Ye., Baisanov S., Grigorovich K., Baisanova A., Toleukadyr R., Saulebek Zh. Recovery of low-carbon ferrochrome with multi-component aluminum-silicon-chrome (Al - Si - Cr) alloy // *Metalurgija.* – 2020. – № 4. – P. 514-516.
- [6] Еднерал Ф.П. Расчеты по электротермии стали и ферросплавов / Ф.П. Еднерал, А.Ф. Филиппов – М.: Metallurgizdat, 1956 – 189 с.
- [7] Е.Н. Акимов. Расчет материального и теплового баланса плавки низкоуглеродистого феррохрома с использованием комплексного восстановителя // Вестник ЮУрГУ. – 2012. – №39. – С.122-124.

Reference

- [1] Akuov A.M., Tolymbekov M.ZH., Izbembetov D.D. i dr. *Termograficheskie issledovaniya hromovogo syr'ya i shiht na ego osnove* // Povyshenie kachestva obrazovaniya i nauchnyh issledovaniy: Mater. mezhd.-nauch. prakt. konf. (Improving the quality of education and research: Materials of the international scientific and pract. conf.) Ekibastuz, Kazakhstan, 2008. 320-323. (in Russ.).
- [2] Almagambetov M.C. *Pazpabotka texnologii vyplavki pafinipovannyx sortov feppoxroma s ppimeneniem fepposilikoaljuminiya* (Development of technology for smelting refined grades of ferrochrome using ferrosilicoaluminium): dic. ... kand. texn. nauk: 05.16.02. Karaganda: ChMI, 2009. 138. (in Russ.).
- [3] Morozov A.N., Lisnyak S.S., Belikov A.M. *Izmenenie sostava i struktury hromistyh rud v processe ih nagrevaniya i vosstanovleniya* (Changes in the composition and structure of chromium ores during their heating and recovery). *Stal'*= *Steel.* 1963. 2. 137-139. (in Russ.).
- [4] Belyaev S. V., Kuzgibekova H. M., Kargina N. A., Zhinova E. V. *Razrabotka matematicheskoy modeli processa izvlecheniya hroma iz hromsoderzhashchego materiala* (Development of a mathematical model of the process of extracting chromium from a chromium-containing material). *Kompleksnoe Ispol'zovanie Mineral'nogo Syr'a. = Complex Use of Mineral Resources.* 2011.6, 33-40. (in Russ.).
- [5] Shabanov Ye., Baisanov S., Grigorovich K., Baisanova A., Toleukadyr R., Saulebek Zh. Recovery of low-carbon ferrochrome with multi-component aluminum-silicon-chrome (Al-Si-Cr) alloy. *Metalurgija.* 2020. 4, 514-516. (In Eng.).
- [6] Edneral F. P. *Raschetny po elektrotermii stali i ferrosplavov* (Calculations on the electrothermy of steel and ferroalloy) / F. P. Edneral, A. F. Filippov - M.: Metallurgizdat, 1956-189. (in Russ.).
- [7] E.N. Akimov. *Raschet material'nogo i teplovogo balansa plavki nizkouglerodistogo ferrohroma s ispol'zovaniem kompleksnogo vosstanovitelya* (Calculation of the material and thermal balance of low-carbon ferrochrome melting using a complex reducing agent). *Vestnik YUURGU = Bulletin Of SUSU.* 2012.39,122-124. (in Russ.).