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**THERMODYNAMIC MODELLING CALCIUMCARBIDE AND A FERROALLOY
FORMATION FROM A SYSTEM OF THE DAUBABA DEPOSIT BASALT – CARBON – IRON**

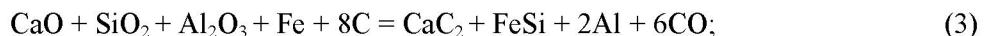
Abstract. The present article contains results of thermodynamic modelling the temperature (from 900 to 2500°C) and iron content (from 0 to 8%) effect on interaction of the Daubaba deposit basalt (40,88% of SiO₂, 19,58% of CaO, 13,36% of Al₂O₃, 15,25% of FeO, 6,68% of MgO, 1,74% of Na₂O, 0,98% of TiO₂, 0,41% of MnO, 0,55% of SO₂) with carbon and formation of calcium carbide and a complex silicon and aluminium-containing ferroalloy. The investigation has been fulfilled using a software package HSC-5.1 based on a Gibbs energy minimum. It was found, that transition degree of calcium into CaC₂ at 2000°C and 45% of C at increase in iron content from 0 to 8% decreases from 54,6% to 42,4%, and transition degree of silicon into the alloy increases and makes 88,1%. Silicon and aluminium concentration in the alloy and the calcium carbide capacity decrease at increase in iron quantity. 87,4-89% of silicon and 50-52% of calcium can be extracted into the alloy and calcium carbide respectively from the basalt in the presence of 45% of carbon, 0-1,9% of iron and temperature of 2028-2043°C. The ferroalloy formed contains 55-56% of Σ(Si+Al); the calcium carbide is characterised by capacity of 240-248 l/kg. The alloy containing silicon and aluminium is a complex ferroalloy – ferrosilicoaluminium of a FS45Al5 grade; the calcium carbide is related to 2-3 grades.

Keywords: basalt, reduction, carbon, temperature, thermodynamic modelling, calcium carbide, ferroalloy.

At present calcium carbide is produced in electric furnaces out of lime and coke at temperature of 1900-2100°C according to the reaction:



The process is characterised by electric energy consumption of 2980-3350 kW·h per 1 t of calcium carbide [1, 2]. A siliceous ferroalloy is obtained at 1600-1800°C from quartz-containing raw materials by a carbothermal way in ore-thermal furnaces. This process is characterized by power consumption from 2200 to 4750 kW·h per 1 t of a ferroalloy (depending on silicon content in it, which changes from 25 to 45%) [3-5]. At the calcium carbide production thermal and electric losses make to 14% from the maximum power [1], and at the siliceous ferroalloy manufacture these losses make 11-14% [6]. Combination of both these processes in one electric furnace permits to reduce the thermal losses in 2 times. The combined processes have been developed for chloride sublimation of off-grade oxide ores [7-9] and processing of oxidized zinc-containing ores [10, 11]. Simultaneous production of calcium carbide and a siliceous ferroalloy may be realized from the raw materials containing SiO₂ and CaO. This raw material group includes 64,1 million tonne of Kazakhstan basalts (Daubaba deposit (19,4 m. t), Tashkursay (15,7 m. t), Dormensay (5,9 m. t), Karauzek (5,7 m. t), Kozyrevsky (3,8 m. t), Chernaya Mazarka (2,8 m. t), Dubersay (10,8 m. t)) [12]. The basalts contain 39-43% of SiO₂, 18-21% of CaO, 12-15% of Al₂O₃, 14-17% of FeO. Now these basalts are mainly used for manufacture of a fibre and a cast stone material [13], which technology is constantly improved [14-17], and also for manufacture of other production [18]. Being used the program HSC-5.1 (Reaction Equations subprogram) [19] we have preliminary calculated ΔG and found that a condition ΔG=0 for joint reduction of Ca, Si, Al oxides on the reactions



is satisfied at 1738 and 2092 K respectively (table 1).

Table 1 – Temperature effect on ΔG (kJ) for the reactions of joint carbothermal reduction of the oxides

Reaction	Temperature, K								
	1173	1373	1673	1738	1773	1873	2073	2092	2173
2	1123,0	724,1	132,3	0	-71,0	-274,6	-679,3	-716	-879,8
3	1057,7	827,9	486,4	429,1	369,7	253,3	22,6	0	-91,9

Studying the possibility of simultaneous production calcium carbide and a silicon and aluminium-containing ferroalloy out of the Daubaba basalt comprising 40,88% of SiO_2 , 19,58% of CaO , 13,36% of Al_2O_3 , 15,25% of FeO , 6,68% of MgO , 1,74% of Na_2O , 0,98% of TiO_2 , 0,41% of MnO , 0,55% of SO_2 has been realized by us by means of thermodynamic modelling with use of the HSC-5.1 software package, in particular the Equilibrium Composition subprogram [19]. The Daubababasalt initial weight was 100 kg. Calculation of the equilibrium is made on the basis of a Gibbs energy minimum principle taking into consideration activities of substances. The developers of the HSC-5.1 program have based on an ideology of a SGTE consortium (Scientific Group Thermodata Europe) which develops, supports and distributes the high-quality databases intended for calculation of an equilibrium composition of chemically reacting systems. The SGTE structure includes specialized scientific centers in Germany, Canada, France, Sweden, the Great Britain and the USA [20]. The error of the calculations made by means of the HSC-5.1 program makes no more than 4-6%.

Thermodynamic modelling influence of temperature (from 1000 to 2300°C) and iron content (from 0 to 8% from the basalt weight) (at 45% of carbon from the basalt weight) on the equilibrium silicon distribution degree in a system of Daubababasalt (DB) – carbon – iron was carried out at pressure of 0,1 MPa. The results of quantitative distribution of the silicon and calcium-containing substances are represented in figures 1 and 2.

Judging by the figures, silicon and calcium in the system are as CaSiO_3 , Al_2SiO_5 , MgSiO_3 , TiO_2 , SiO_2 , FeSi , Fe_3Si , TiSi , CaSi , Si and SiO_{gas} , CaO , CaC_2 , Ca_{gas} , and aluminium as Al_2SiO_5 , Al_2O_3 and Al . The information about the initial temperature of formation of the compounds (T_i , $^{\circ}\text{C}$) is given in table 2.

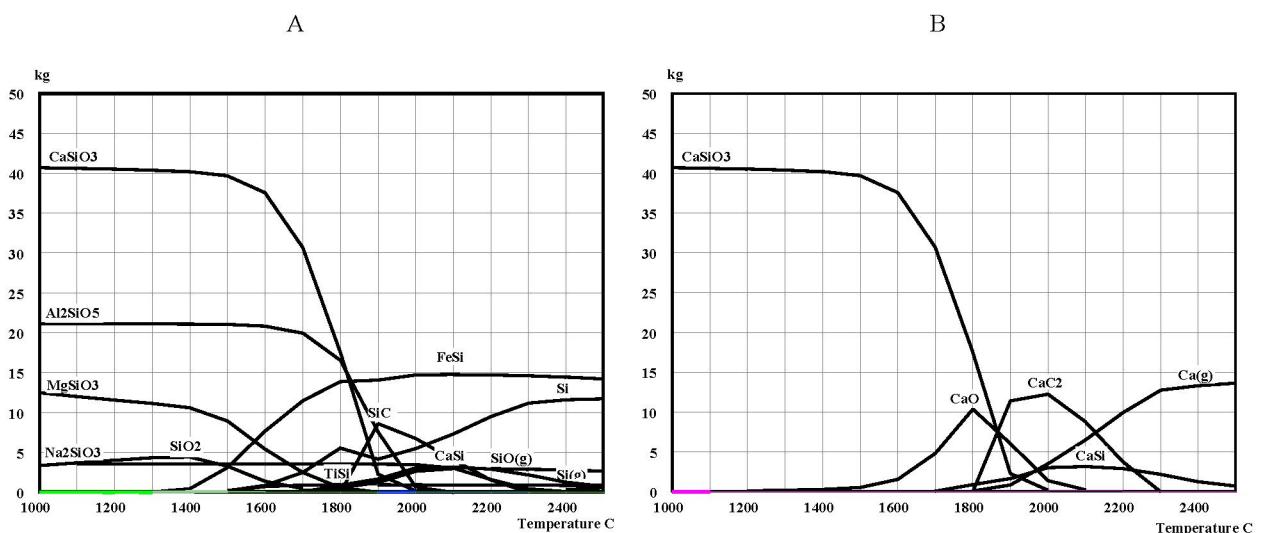


Figure 1 – Temperature effect on quantitative distribution of the Si and Ca containing substances in the system of DB-45%Ca at absence of iron:

A – silicon-containing substances, B – calcium-containing substances

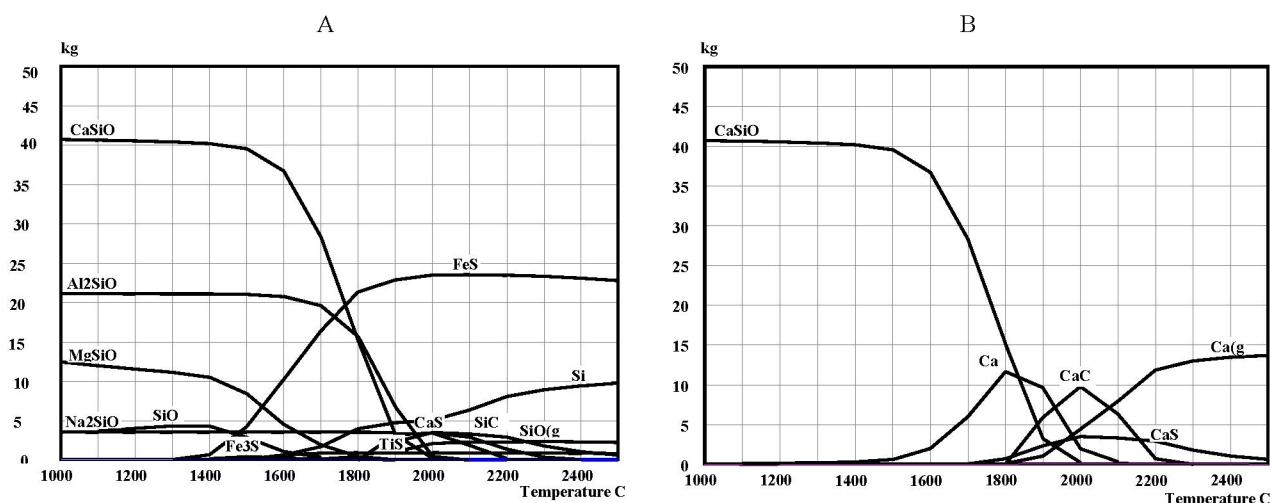


Figure 2 – Temperature effect on quantitative distribution of the Si and Ca containing substances in the system of DB-45% C at presence of 8% of iron:
A – silicon-containing substances, B – calcium-containing substances

Table 2 – Initial formation temperature (T_i , °C)

Substances	SiC	TiSi	CaSi	Si	CaC ₂	Ca _{gas}	Al	Fe ₃ Si	SiO _{gas}	FeSi
T_i , °C (8% of Fe)	1900	1500	1700	1400	1800	1800	1700	1300	1500	1300

As follows from the table 2 the simultaneous formation of a ferroalloy on the basis of FeSi, Fe₃Si, TiSi, Si, SiC, CaSi, Al occurs at temperature above 1800°C.

The calculation results of equilibrium transition degree (α , %) of Si and Al into the alloy (α Si (alloy) and α Al (alloy)) and calcium into calcium carbide (α Ca (CaC₂)) depending on temperature and iron amount are represented in figures 3 and 4.

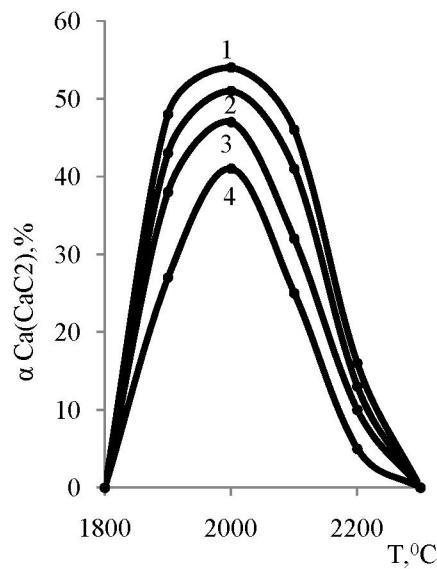


Figure 3 – Temperature and iron content effect on α Ca(CaC₂) at 45% of C:
1 – 0% of Fe, 2 – 2% of Fe, 3 – 4% of Fe, 4 – 8% of Fe

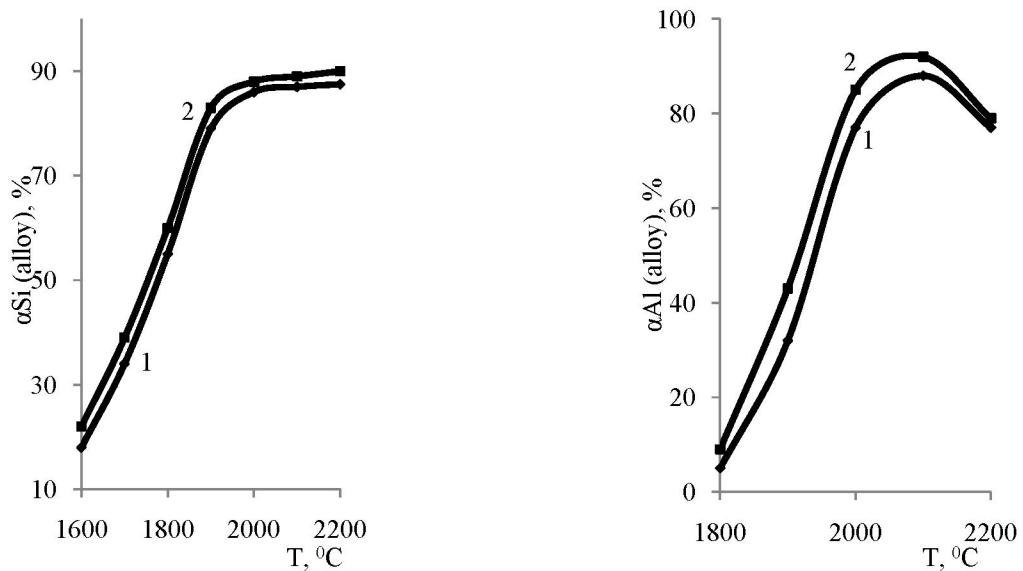


Figure 4 – Temperature and iron content effect on $\alpha\text{Si}(\text{alloy})$ and $\alpha\text{Al}(\text{alloy})$ at 45% of C: 1 – 0% of Fe, 2 – 8% of Fe

As follows from the figure 3, the increase in iron content from 0 to 8% from the basalt weight (at 45% of C from the basalt weight) decreases $\alpha\text{Ca}(\text{CaC}_2)$ from 54,6% to 42,4% at 2000°C according to the equation:

$$\alpha\text{Ca}(\text{CaC}_2) = 54,44 - 1,5114 \text{ Fe}. \quad (4)$$

The decrease in αCa (CaC_2) at temperatures above 2000°C can be caused by the CaC_2 decomposition [21]:



The inverse picture is observed for $\alpha\text{Si}(\text{alloy})$ (figure 4). The increase in iron content from 0 to 8% at 45% of C allows to raise αSi (alloy) in the temperature interval of 1600-2000°C and to achieve 88,1-90,24% at 2000-2200°C.

An important technological parameter of the developed technology is silicon and aluminium content in the produced ferroalloy (C_{Si} , C_{Al}) and CaC_2 content in the technical carbide (C_{CaC_2}). From the figure 5 it

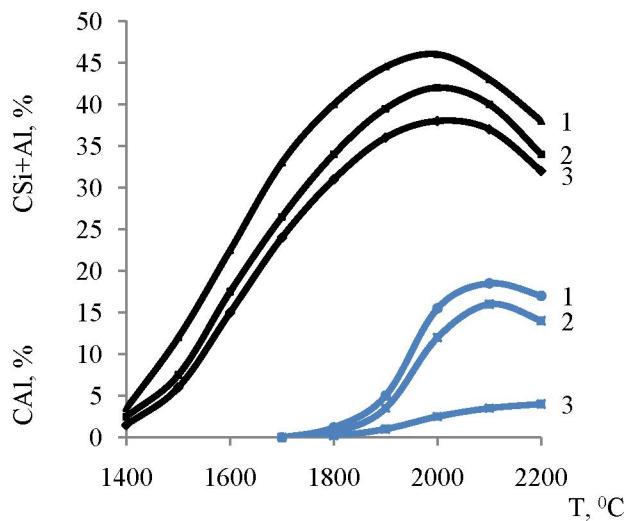


Figure 5 – Temperature and iron content effect on Si and Al content and total Si+Al content in the ferroalloy in the system of DB-20%C-nFe: 1 – 0% of Fe, 2 – 4% of Fe, 3 – 8% of Fe

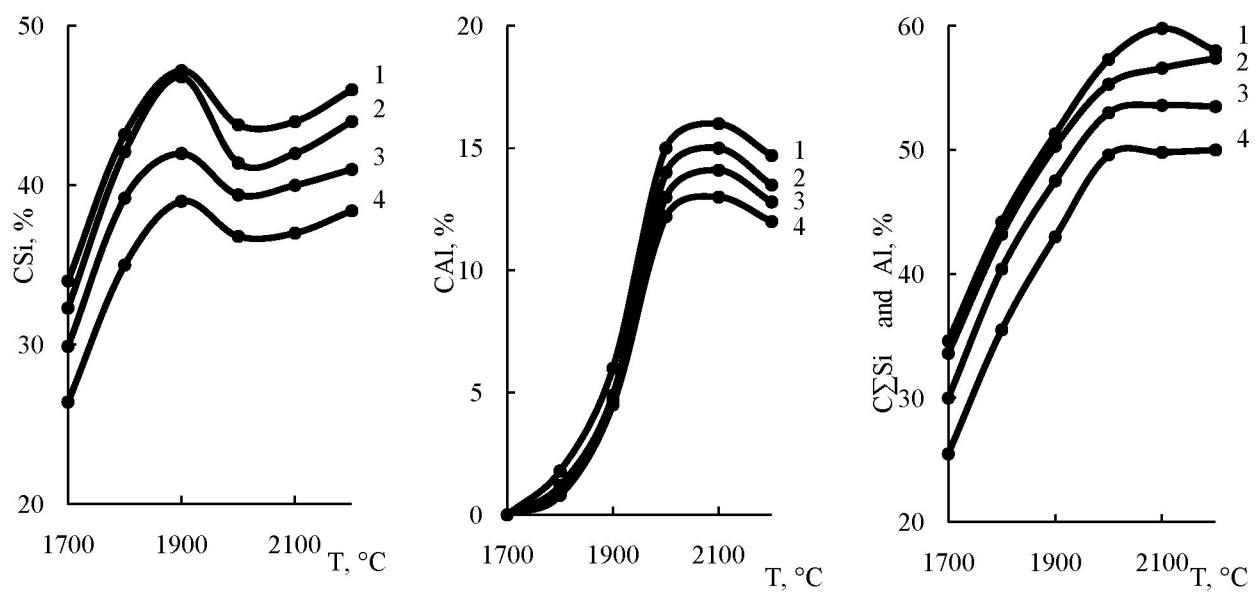


Figure 6 – Temperature and iron content effect on Si and Al content and total Si+Alcontent in the ferroalloy in the system DB-45% C-nFe: 1 – 0% of Fe, 2 – 2% of Fe, 3 – 4% of Fe, 4 – 8% of Fe

is obvious, that at 20% of carbon in the system the increase in iron amount from 0 to 8% reduces aluminiumconcentration and total silicon and aluminiumconcentration ($C_{\Sigma Si+Al}$)in an alloy. Maximum $C_{\Sigma Si+Al}$ (45,6%) is reached at 2000°C in absence of iron. With growth of the carbon quantity to 45% the influence pattern of iron on Siand Alconcentration in the alloy does not change. However the pattern of temperature effect on C_{Si} and C_{Al} is a little bit other (figure 6). The increase in temperature to 1900°C raises C_{Si} . Then we see the minimum C_{Si} at 2000-2200°C and its increase at temperature above 2200 °C. Aluminium contentin the alloy during the temperature growth passes through a maximum at 2100°C and makes13,1% at 8% of Fe. With increase in the temperature the totalSi and Al content in the alloy increases. In the temperature interval of 2000-2200°C and 2-8% of iron $C_{\Sigma Si+Al}$ makes 49-58%.

The temperature and iron amountinfluence on the calcium carbide capacityis shown in figure 7. As follows from the Figure the iron content increase leads to the capacity reduction. So, if at 2100°C in absence of iron the calcium carbide capacity makes 265 l/kg, then at 8% of Fe it decreases to 244,1 l/kg.

For determination of the optimum temperature and iron amount we have fulfilled researches by a rotatablematrix planning method in respect to a bifactorial experiment [22]. The optimization parameters

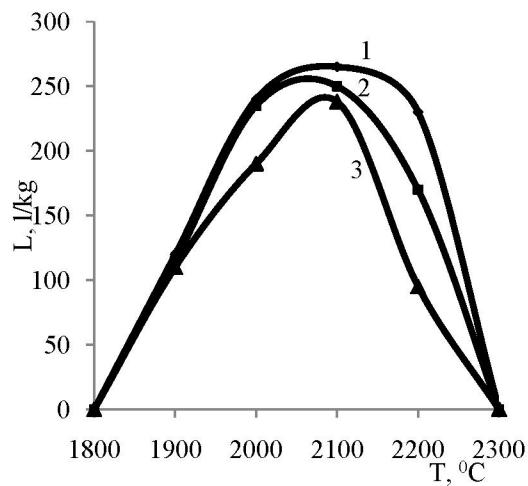


Figure 7 – Temperature and iron content effect on the CaC_2 capacity:
1 – 0% of Fe, 2 – 2% of Fe, 3 – 4% of Fe, 4 – 8% of Fe

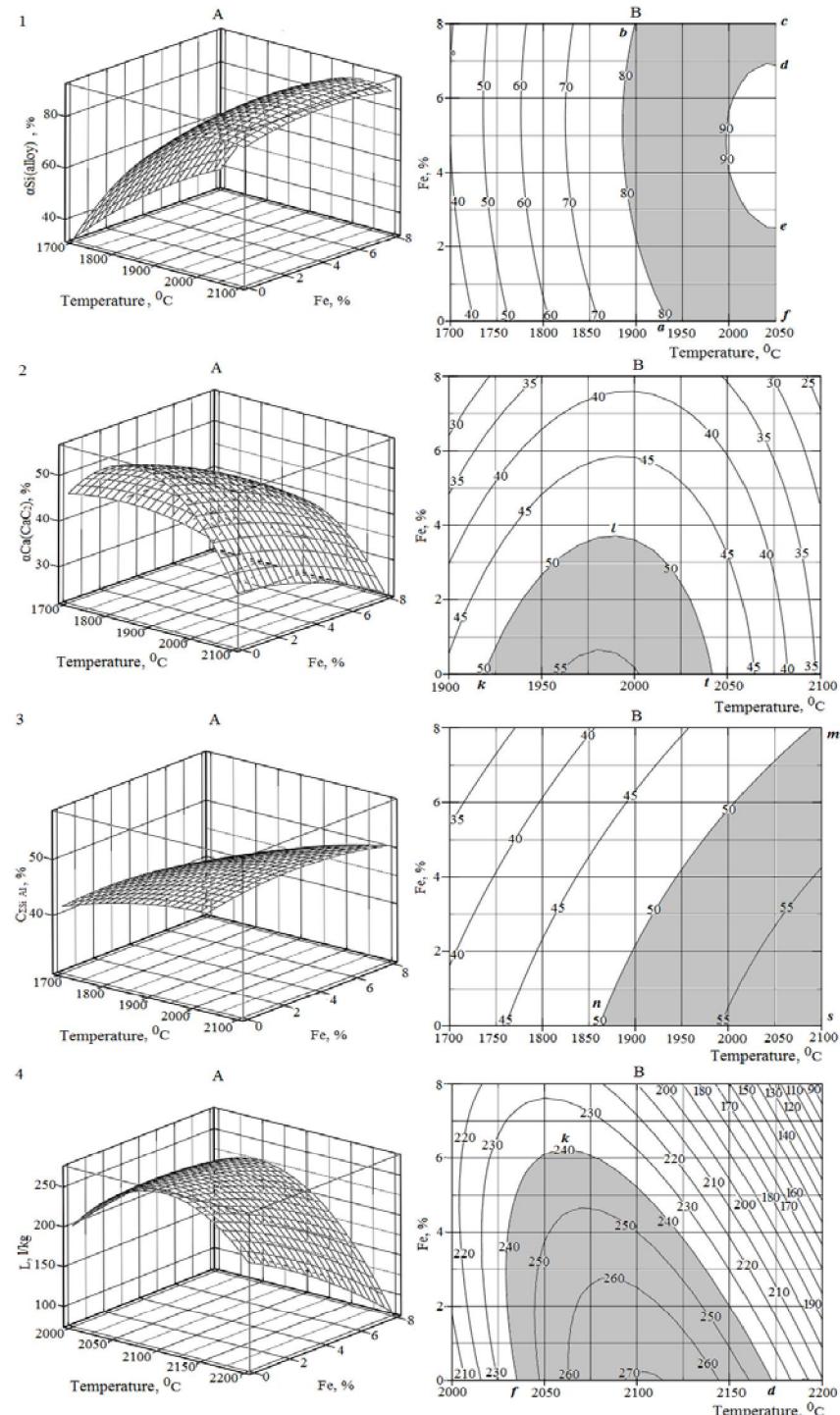
are α Si (alloy), α Ca (CaC_2), $C_{\Sigma \text{Si} + \text{Al}}$ in the alloy, calcium carbide capacity L, and independent factors are iron content (from the basalt weight) (Fe, %), temperature (T, $^{\circ}\text{C}$). We have obtained the following regression equations:

$$\alpha_{\text{Si}_{(\text{alloy})}} = -1700.11 + 1.738 \cdot T + 5.036 \cdot \text{Fe} - 4.226 \cdot 10^{-4} \cdot T^2 - 0.223 \cdot \text{Fe}^2 - 1.433 \cdot 10^{-3} \cdot T \cdot \text{Fe} \quad (6)$$

$$\alpha_{\text{Ca}(\text{CaC}_2)} = -5904.185 + 6.018 \cdot T - 14.002 \cdot Fe - 1.519 \cdot 10^{-3} \cdot T^2 - 0.141 \cdot Fe^2 + 6.539 \cdot 10^{-3} \cdot T \cdot Fe \quad (7)$$

$$C_{\Sigma Si+Al} = -199,967 + 0,223 \cdot T - 2,764 \cdot Fe - 4,8 \cdot 10^{-5} \cdot T^2 - 6,964 \cdot 10^{-2} \cdot Fe^2 + 1,131 \cdot 10^{-3} \cdot T \cdot Fe \quad (8)$$

$$L_{\text{CaC}2} = -28470,14 + 27,323 \cdot T + 184,5 \cdot Fe - 6,493 \cdot 10^{-3} \cdot T^2 - 0,605 \cdot Fe^2 - 8,916 \cdot 10^{-2} \cdot T \cdot Fe \quad (9)$$



Being used the MathCad program [23] on the basis of the equations 6-9 we have constructed response surfaces and their horizontal sections (figure 8). Judging by figure 8, αSi from 80 to 90% is in the area $abcdef$ ($1880-2050^{\circ}\text{C}$ and 0-8% of Fe). The extraction degree of Ca into CaC_2 from 50 to 56% is in the area klt ($1918-2006^{\circ}\text{C}$ and 0-3,7% of Fe). The total Si and Al content in the alloy from 50 to 58% is in the area nms ($1860-2100^{\circ}\text{C}$ and 0-4,2% of Fe). The calcium carbide with capacity of 240-271 l/kg is formed in the area fkd ($2070-2100^{\circ}\text{C}$ and 0-6,15% of Fe). From figure 8 it is follows, that $\alpha\text{Ca}(\text{CaC}_2)$ is substantially less, than αSi (alloy). Therefore the optimum should be searched proceeding from the maximum $\alpha\text{Ca}(\text{CaC}_2)$. Figure 9 represents the superimposed information about influence of temperature and iron amount on αSi (alloy), $\alpha\text{Ca}(\text{CaC}_2)$, $C_{\Sigma\text{Si+Al}}$ in the alloy and capacity L. At the construction the minimum limiting indices were calcium carbide capacity of 240 l/kg (calcium carbide of 2 and 3 grades), $\alpha\text{Ca}(\text{CaC}_2) \geq 50\%$, $\alpha\text{Si}(\text{alloy}) \geq 87\%$, $C_{\Sigma\text{Si+Al}} \geq 55\%$.

The plane $abcd$ in figure 9 is the technological area respective to set limits. Values of temperature and iron content in the border points of the $abcd$ area are represented in table 3.

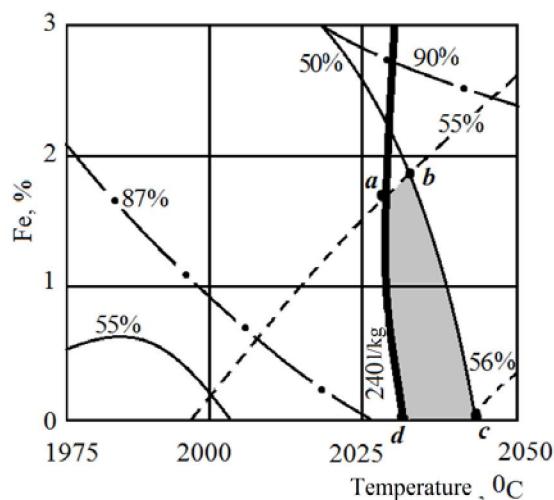


Figure 9 – 1 Superimposed information about temperature and iron amount effect on $\alpha\text{Si}(\text{alloy})$ – (- · - -), $\alpha\text{Ca}(\text{CaC}_2)$ – (—), $C_{\Sigma\text{Si+Al}}$ (- - -) and L (—)

Table 3 – Technological parameters in the border points

Point in figure 9	Technological parameter					
	αSi , %	$\alpha\text{Ca}(\text{CaC}_2)$, %	L, l/kg	$C_{\Sigma\text{Si+Al}}$	T, $^{\circ}\text{C}$	Fe, %
a	88,6	50,8	240	55,0	2028	1,8
b	89,0	50,0	242	55,0	2032	1,9
c	88,0	50,0	248	56,0	2043	0
d	87,4	52,0	240	55,3	2031	0

Thus from the Daubaba basalt at presence of 45% of carbon and 0-1,9% of iron at $2028-2043^{\circ}\text{C}$ it can be simultaneously extracted 87,4-89,0% of silicon into the ferroalloy and 50-52% of calcium in calcium carbide. In this case the calcium carbide has capacity of 240-248 l/kg, and the total silicon and aluminium content in the alloy makes 55-56%. Such the alloy concerns to ferrosilicoaluminium of a FS45Al5 grade[24], and the calcium carbide to 2-3 grade.

Conclusion. On the basis of the results obtained at the thermodynamic modelling the Daubaba basalt – carbon interaction at presence of iron we may draw following conclusions:

- formation of calcium carbide in the system occurs at 1800°C , iron silicides – at 1300°C , silicon and aluminium – at $1400-1700^{\circ}\text{C}$;

- transition degree of calcium into CaC_2 at 2000°C and 45% of C at increase in iron content from 0 to 8% decreases from 54,6% to 42,4%, and transition degree of silicon into the alloy increases and makes 88,1%;

- silicon and aluminium concentration in the alloy and the calcium carbide capacity decrease at increase in iron content;

- from the Daubaba basalt at presence of 45% of carbon and 0-1,9% of iron at 2028-2043°C it can be simultaneously extracted 87,4-89,0% of silicon into the ferroalloy and 50-52% of calcium in calcium carbide; the calcium carbide formed has capacity of 240-248 l/kg, and $\Sigma Si + Al$ in the alloy makes 55-56%;

- the alloy containing silicon and aluminium is a complex ferroalloy – ferrosilicoaluminium of aFS45Al5 grade, and the calcium carbide formed concerns to 2-3 grade.

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ДАУБАБА КЕНОРНЫНЫҢ БАЗАЛЬТЫ-КӨМІРТЕК-ТЕМІР ЖҮЙЕСІНЕН ФЕРРОҚОРЫТПА ЖӘНЕ ҚАЛЬЦИЙ КАРБИДІНІҢ ТҮЗІЛУІН ТЕРМОДИНАМИКАЛЫҚ МОДЕЛЬДЕУ

Аннотация. Мақалада Si және Al құрайтын, кешенді ферроқорытпа мен қальций карбидінің түзілуімен көміртегімен Даубаба (40,88% SiO₂, 19,58% CaO, 13,36% Al₂O₃, 15,25% FeO, 6,68% MgO, 1,74% Na₂O, 0,98% TiO₂, 0,41% MnO, 0,55% SO₂) кенорнының базальтымен есерлесуіне темір (0-ден 8%-ға дейін) және температураның (1000-ден 2500-ға дейін °C) есерін термодинамикалық модельденуі бойынша жұмыс қорытындысы келтірілген. Зерттеу Гиббс энергиясының минимумына негізделген, HSC-5.1 кешенді бағдарламаны қолдана отырып жүргізілді. Нәтижесінде 2000 °C және 45% С, темір мөлшерін 0 ден 8% жоғарылатқанда Ca-dің CaC₂ өту дәрежесі 54,6% дан 42,4% -ға төмендейді, ал Si балқымаға өту дәрежесі 88,1% ұлғаяды; темір мөлшерінің артуында балқымадағы Si және Al концентрациясы және қальций карбидінің литражы төмендейді; 45% көміртегі қатысуында базальттан 0-1,9 % Fe және 2028-2043 °C бір мезетте балқымаға 87,4-89% Si және 50-52% Ca қальций карбидіне бөліп алады; түзілген ферроқорытпа 55-56% ΣSi және Al құраса, 242-248 л/кг литражбен қальций карбидімен сипатталады. Si және Al құрамдас балқыма кешенді ферроқорытпаға жатады, яғни ФС45Al5 маркалы ферросиликоалминийге, ал қальций карбиді 2-3 сортқа ие болады.

Түйін сөздер: базальт, қалына келтіру, көміртек, температура, термодинамикалық модельдеу, қальций карбиді, ферроқорыта.

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ТЕРМОДИНАМИЧЕСКОЕ МОДЕЛИРОВАНИЕ ОБРАЗОВАНИЯ КАРБИДА КАЛЬЦИЯ И ФЕРРОСПЛАВА ИЗ СИСТЕМЫ БАЗАЛЬТ ДАУБАБИНСКОГО МЕСТОРОЖДЕНИЯ – УГЛЕРОД-ЖЕЛЕЗО

Аннотация. В статье приводятся результаты работы по термодинамическому моделированию влияния температуры (от 900 до 2000°C) и железа (от 0 до 8%) на взаимодействие базальта месторождения Даубаба (40,88% SiO₂, 19,58% CaO, 13,36% Al₂O₃, 15,25% FeO, 6,68% MgO, 1,74% Na₂O, 0,98% TiO₂, 0,41% MnO, 0,55% SO₂) с углеродом с образованием карбида кальция и комплексного ферросплава, содержащего кремний и алюминий. Исследования проводили с использованием программного комплекса HSC-5.1, основанного на минимуме энергии Гиббса. Найдено, что степень перехода кальция в CaC₂ при 2000 °C и 45%. С при увеличении количества железа от 0 до 8% уменьшается от 54,6% до 42,4%, а степень перехода кремния в сплав возрастает, составляя 88,1%. Концентрация кремния и алюминия в сплаве и литраж карбига кальция снижаются при увеличении количества железа; в присутствии 45% углерода, 0-1,9 % Fe при 2028-2043 °C из базальта можно одновременно в сплав извлечь 87,4-89% Si и 50-52% кальция в карбид кальция. Образующийся ферросплав содержит 55-56% ΣSi и Al, карбид кальция характеризуется литражом 240-248 л/кг. Сплав, содержащий кремний и алюминий относится к комплексному ферросплаву – ферросиликоалминию марки ФС45Al5, а карбид кальция обладает 2-3 сортностью.

Ключевые слова: базальт, восстановление, углерод, температура, термодинамическое моделирование, карбид кальция, ферросплав.

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REFERENCES

- [1] Ershov V.A. (1984). Electrothermal processes of chemical technology. Chemistry, Leningrad, Russia (in Rus.).
- [2] Bogdanov S.P., Kozlov K.B., Lavrov B.A. (2009). Electrothermal processes and reactors. Prospect of Science. St. Petersburg, Russia. ISBN 978-5-903090-32-7 (in Rus.).
- [3] Ednreal F.P. (1977). Electrometallurgy of steel and ferroalloys. Moscow, Russia (in Rus.).
- [4] Gasik M. (2013). Handbook of Ferroalloys: Theory and Technology 1st Edition. Butterworth-Heinemann, USA. ISBN 9780080977539.
- [5] Moniz B.J. (2012). Metallurgy. Amer Technical Pub, USA. ISBN 978-0826935229.
- [6] Ferroalloys furnace [Electronic resource]. URL:<http://lektssi.com/2-67960.html> (Date of access: 03.01.2018).
- [7] Tleukulov O.M. (1986). Integrated non-waste chloride processing of polymetallic oxidized raw materials. Leningrad, Russia (in Rus.).
- [8] Melnik M.A. (1992). Physicochemical basis and complex chloride technology of processing zinc-oligoitic ores of Zhayremsky deposit. Alma-Ata, Kazakhstan.
- [9] Shevko V.M., Daribaev Zh.B. (2004). Agglomeration-chlorinating firing of tailings of enrichment and overburden. IKTU, Kentau, Russia (in Rus.).
- [10] Shevko V.M., Kapsaljamov B.A., Bishimbaev V.K., Kolesnikov A.S., Kartbaev S.K. (2009). Complex electrothermal processing of clinkers for the waelz - process of oxide Ajisai zinc-containing ores. SKSU named after M. Auezov, Shymkent, Kazakhstan. ISBN 9965-1-9173-5 (in Rus.).
- [11] Shevko V.M., Ajtkulov D.K., Atamkulov B.B., Izbasanov K.S., Najmanbaev M.A. (2017). Complex electrothermal processing of poor oxide ore of the Achisay deposit. News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and engineering sciences. [Kompleksnaja jekletrotermicheskaja pererabotka bednoj oksidnoj rudy Achisajskogo mestorozhdenija // Izvestija nacional'noj akademii nauk Respubliki Kazahstan. Serij geologii i tchnicheskikh nauk] 4: 177-183 (in Rus.).
- [12] Bajbatsha A.B. (2008). Geology of Mineral Deposits - Tutorial. KNTU, Almaty, Kazakhstan (in Rus.).
- [13] Dzhigiris D.D., Makhova M.F. (2002). Basis for the production of basalt fibers and articles: Monograph. Heat-and-powerengineer. Moscow, Russia (in Rus.).
- [14] Aspanova L.G. (2000). Method for obtaining basalt fiber and a device for its implementation [Sposob poluchenija bazal'tovogo volokna i ustrojstvo dlja ego osushhestvlenija]. Patent of the Russian Federation 2149841 [Patent Rossijskoj Federacii 2149841] (in Rus.).
- [15] Bagrijancev G.I., Koryhaev V.V., Kulagina N.V. and others (2009). Method of obtaining fiber from mineral raw materials [Sposob poluchenija volokna iz mineralnogo syrja]. Patent of the Russian Federation 2352531 [Patent Rossijskoj Federacii 2352531].
- [16] Osnoc S.P., Ahmadeev V.F. (2010). Basalt continuous fiber [Bazaltovoe nepreryvnoe volokno]. Patent of the Russian Federation 2381188 [Patent RossijskojFederacii 2381188].
- [17] Babievskaia I.Z., Gavricev K.S. and others (2007) Method for producing basalt fiber [Sposob poluchenija bazaltovogo volokna]. Patent of the Russian Federation 2297986 [Patent Rossijskoj Federacii2297986].
- [18] Aknazarov S.H., Lukjashhenko V.G., Messerle V.E. (2013). Method for processing slime of chromate production [Sposob pererabotki shlama hromatistogo proizvodstva]. Innovation patent of the Republic of Kazakhstan 27146 [Innovacionnyj patent Respubliki Kazahstan 27146].
- [19] Roine A. (2002). Outokumpu HSC Chemistry for Windows. Chemical reactions and equilibrium software with extensive thermochemical database. Outokumpu research, Pori.
- [20] Scientific Group ThermoData Europe: [Electronic resource]. URL:<http://sgte.net/en/> (Date of access: 03.01.2018).
- [21] Kozlov K.B., Lavrov B.A. (2011). Calcium carbide production in an arc furnace and its analysis. SPbGTI, Saint-Petersburg, Russia (in Rus.).
- [22] Ahnazarova S.A., Kafarov B.V. (1978). Methods for optimizing the experiment in the chemical industry. High school, Moscow, Russia.
- [23] Ochkov V.F. (2007). Mathead 14 for students, engineers and designers. BHV-Petersburg, St.-Petersburg, Russia (in Rus.).
- Gasik M.I., Ljakishev N.P. (1999). Theory and technology of electrometallurgy of ferroalloys. JV Intermet Enginee-ring, Moscow, Russia (in Rus.).