MANGANESE FERROALLOYS PRODUCTION FROM RUSSIAN MANGANESE ORES *

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After the collapse of the Soviet Union Russia lost its developed manganese ore mining deposits. Demand for manganese ferroalloys in Russia is about 600-650 thsd. tons a year. Assortment of manganese ferroalloys includes high-, medium- and low-carbon ferromanganese, silicomanganese and manganese metal. Most of bulk manganese ferroalloys (~ 60% of high-carbon ferromanganese and silicomanganese) are imported from abroad. Medium- and low-carbon ferromanganese and electrothermic manganese metal are 100% imported (mainly from Ukraine and China) [1].

High-carbon ferromanganese in Russia is smelted mainly in blast furnaces at JSC "Kosaya Gora Iron Works" (JSC "KGIW") and JSC "Satka Pig-iron Smelting Works" (JSC "SHPZ") from imported manganese ores [2]. Silicomanganese is occasionally smelted at JSC "Chelyabinsk Electrometallurgical Works" (JSC "Chemk") mainly from imported ores from Kazakhstan.

It is important for Russia to increase production volumes of high-carbon ferromanganese and silicomanganese from domestic ores. Development of production technologies for medium- and low-carbon ferromanganese and manganese metal from domestic ores becomes vital for the country due to import substitution in a present international situation.

Reserves of manganese ores in Russia are estimated approximately at a level of 290 million tons, and probable reserves are more than 1 billion tons [3]. There are three main types of manganese ores in Russia: carbonateous, oxide and oxidated.

Poor manganese carbonateous ores (19.8% Mn) with high phosphorus concentration (more than 0.2 – 0.3%) prevail (90.2%) in proved reserves, whether a share of oxide ores with 23-26% Mn is only 6%. Manganese ores deposits are located in Kemerovo region (Usinskoe), Krasnoyarsk (Porozhinskoye), Ural (Severouralskoye), Komi Republic (Parnokskoye), Irkutsk region (Novonikolayevskoye) and others (see Fig. 1).

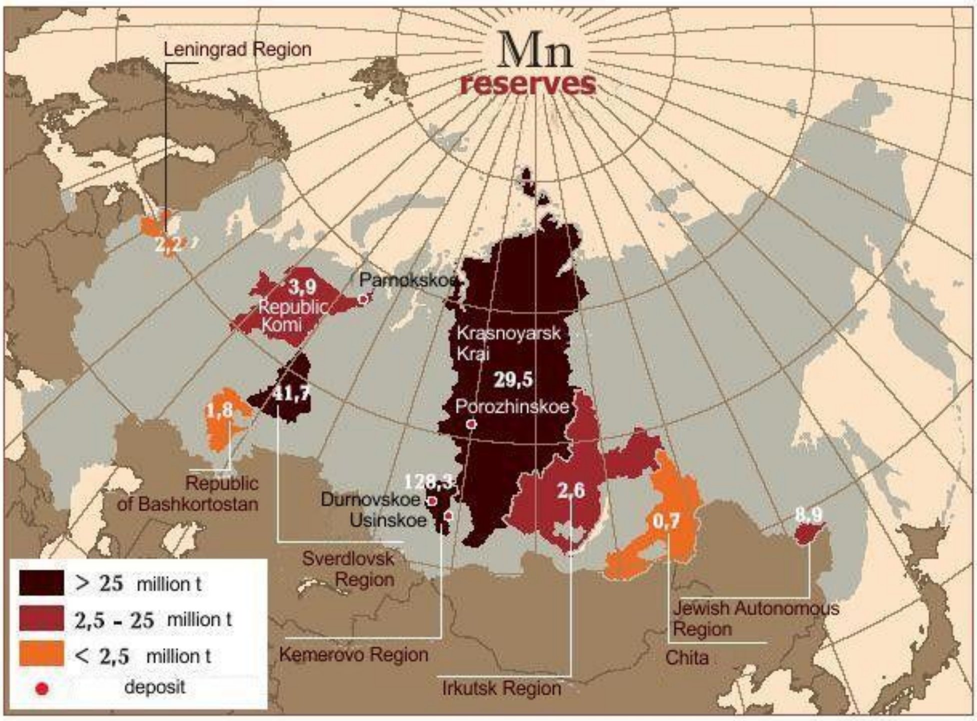

Fig. 1. Manganese ores deposits in Russia

Manganese ores of these deposits have low manganese content and high phosphorus concentration. Most of the mining deposits are unefficient and located in regions difficult to access. Data on reserves of manganese ores in Russian regions are given in Table 1. Mining of manganese ores on the territory of the Russian Federation does not occur at present time [3, 4] though it is of immense importance to have operating mining deposits for protection of Russian metallurgical industry which requires sufficient volumes of manganese ferroalloys.

It’s hard to agree with the authors [5] that there is no reliable solution for the development of domestic manganese ores deposits such as Usinskoye. It is also criticized by the editorial staff in a special review of the article, that «produced proofs in this article are insufficient for such a categorical judgment on inexpediency of development of mining and processing facilities for production of manganese-containing products on the basis of domestic manganese ores deposits in Russia.

Research and development programs are carried out at present for involvement of domestic manganese ores into process of ferroalloys production in Russia to meet a growing demand of steelmaking industry. Poor manganese ores with high phosphorus content must undoubtedly be enriched. In this processes a sufficient part of manganese is lost with by-products: slags, sludge and tailings. Manganese extraction value from ore to commercial ferroalloys reaches 50 – 55% [6].

Table 1. Reserves of manganese ores in Russian regions [3]

#	Region	Reserves			Probable reserves
		$A+B+C_1$	C_2	total	
1	Sverdlovsk region	41.3	–	41.3	49.2
2	Kemerovo region	98.5	–	98.5	150.4
3	Khabarovsk region	6.5	2.5	9.0	53.2
4	Komi Republic	–	3.9	3.9	101.2
5	Orenburg region	–	4.2	4.2	31.0
6	Irkutsk region	–	4.8	4.8	36.2
7	Krasnoyarsk region	–	121.5	121.5	201.0
8	Republic of Bashkortostan	–	–	–	90.0
9	Altay region	–	–	–	200.0
10	Arkhangelsk region	–	–	–	130.0
TOTAL		146.3	136.9	283.2	1042.2

The problem for Russian metallurgists is an involvement of domestic manganese ores into technological process of ferroalloys production and smelting of all range of ferroalloys. This issue is complicated by ferroalloys quality specifications and requirements to engineering-and-economical performance.

Usinskoye mining deposit is one of the most promising and biggest in Russia. It was discovered in 1939 and situated in the South-East of Kemerovo region and 70 km North-East from the city of Mezhdurechensk in mountain taiga forest (see fig. 2). There are two genetic types of manganese ores at this mining deposit: carbonateous and oxidated (see table 2). The share of carbonateous ores is 94% and that of oxidated ores is 6% while the share of mixed type ores is negligible.

The problem of ferroalloys production from manganese ores of Usinskoye mining deposit (18-22% Mn, 0,2-0,3% P) was studied [4, 7-11] but still requires further investigation.

Use of modern methods of concentration such as X-ray radiometric separation allows producing several types of concentrates (table 3) from manganese ores of Usinskoye mining deposit. Different technologies for production of manganese ferroalloys were considered for manganese concentrates of Usinskoye deposit. Optional variants are described below.

Fig. 2. Location of Usinskoe mining deposit in Kemerovo region

Table 2. Chemical composition of manganese ores of Usinskoe mining deposit, % wt

Ore	Mn	MnO	MnO_2	P	P_2O_5	Fe	FeO	Fe_2O_3	SiO_2
Carbonateous	19.23	24.83	–	0.152	0.35	4.92	5.04	1.42	17.44
Oxidated	24.37	1.08	36.68	0.235	0.54	8.26	–	11.51	25.54
Carbonateous	18.18	2.02	3.18	0.16	0.17	0.80	0.96	24.01	
Oxidated	5.60	3.36	1.44	0.15	0.17	0.20	0.11	13.44	

Table 3. Chemical composition of X-ray radiometric separation of concentrates

Elements	Concentrate type							
	Carbonateus					Oxide		
	I grade	II grade	jigging			coarse size	jigging	
	20–100 mm	20–100 mm	10–20 mm	4–10 mm	0–4 mm	10–80 mm	4–10 mm	0–4 mm
Mn	36.00	25.20	24.00	23.50	23.30	35.83	35.00	34.20
P	0.16	0.15	0.14	0.14	0.14	0.216	0.220	0.230
Fe	3.20	3.30	3.60	5.00	5.00	11.07	10.90	10.54
SiO_2	9.49	13.32	13.87	14.17	14.29	12.72	13.20	13.60
CaO	7.44	14.95	15.70	16.03	16.17	2.36	2.36	2.40
MgO	1.76	2.85	2.99	3.05	3.08	1.52	1.51	1.48
Al_2O_3	1.18	1.40	1.47	1.50	1.52	1.84	1.89	1.99
BaO	0.10	0.16	0.16	0.16	0.17	0.20	0.20	0.22
TiO_2	0.08	0.09	0.11	0.12	0.12	0.14	0.14	0.15
Na_2O+K_2O	0.20	0.25	0.35	0.36	0.37	0.20	0.20	0.20
S	0.80	0.90	0.90	0.96	0.96	0.08	0.09	0.09
loss on ignition	26.58	27.20	26.30	25.95	25.73	7.72	9.49	10.70
moisture	1.0	1.0	13.6	15.0	16.0	3.2	16.0	17.0
P/Mn	0.0044	0.0059	0.0058	0.0060	0.0060	0.0060	0.0060	0.0063
Fe/Mn	0.089	0.131	0.150	0.213	0.215	0.309	0.311	0.308

Blast-furnace smelting of high-carbon ferromanganese (flux method) from I grade carbonateous concentrate is planned at the **first stage** of industrial engineering. Other concentrates (II grade and jigging carbonateous, oxide) are suitable for smelting of silicomanganese only. This alloy type requires construction of a smelting shop equipped with submerged arc furnaces. Organization of silicomanganese production is a basis for medium-carbon ferromanganese from I grade carbonateous concentrates. This technological process requires construction of refining furnaces in the smelting shop. Technological scheme of manganese ferroalloys smelting from manganese concentrates of Usinsloye deposit at the first stage of industrial engineering is shown in Fig. 3.

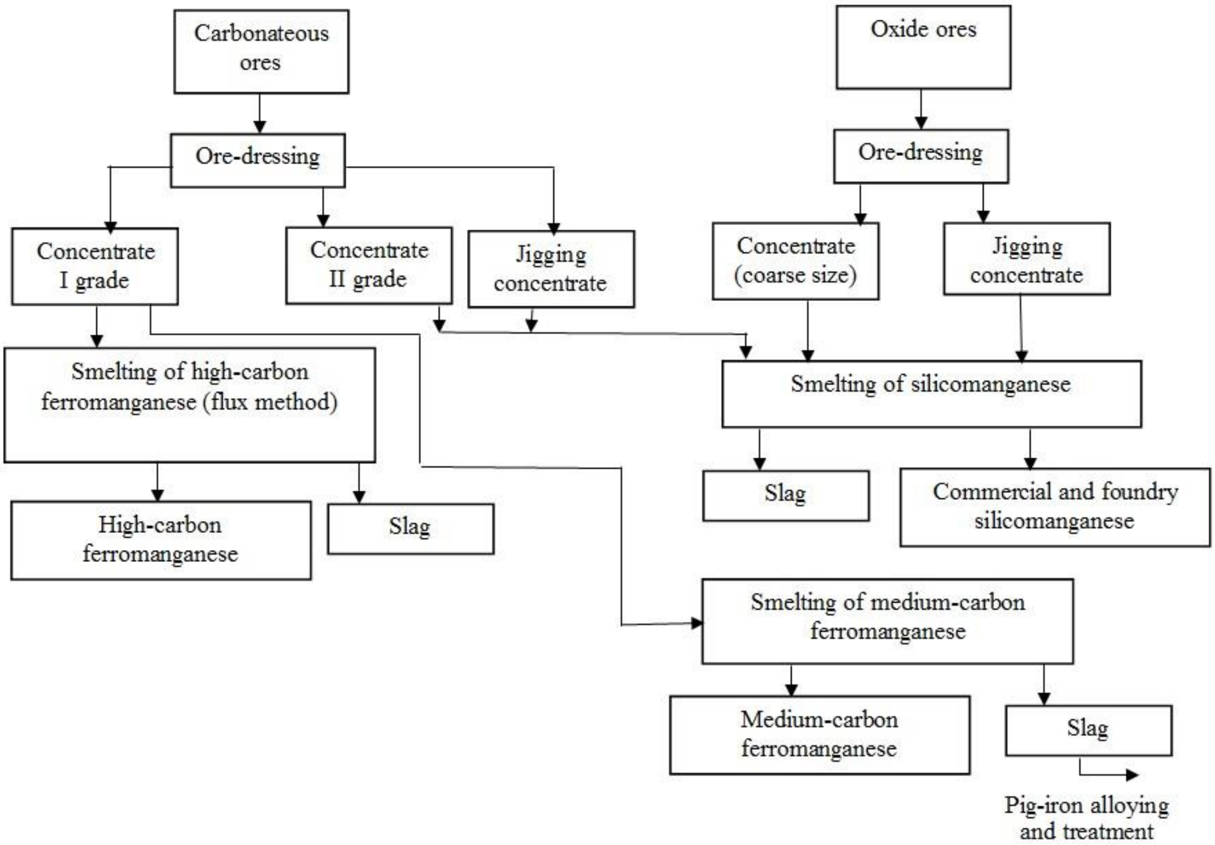

Fig. 3. Technological scheme of manganese ferroalloys production from manganese raw materials of Usinskoye deposit (first stage)

High-carbon ferromanganese (flux method). There are raw materials requirements for production of standard high-carbon ferromanganese such as ratio P/Mn≤0,0045 and Fe/Mn≤0,10. Only a carbonateous concentrate (I grade) meets these requirements among other materials (see table 3). Calculated chemical composition of metal and slag for production of high-carbon ferromanganese in a blast-furnace is given below:

Chemical composition of high-carbon ferromanganese, % wt.

Mn	Fe	C	Si	P	S
79.37	12.41	6.45	1.36	0.39	0.02

Chemical composition of high-carbon ferromanganese slag, % wt.

Mn	FeO	SiO_2	CaO	Al_2O_3	MgO	P_2O_5	S
12.15	0.73	32.13	37.82	5.97	6.20	0.060	1.49

Calculated specific consumption of carbonateous manganese concentrate (I grade) is 2756 kg/ton high carbon ferromanganese FeMn78.

Ferrosilicomanganese. Carbonateous concentrates (II grade and jigging) can only be used for production of silicomanganese due to low concentration of manganese and high phosphorus content. Oxidated manganese (with the share of proved reserves of Usinskoye deposit ~6%) and carbonateous ores will be extracted first. After working out of oxidated manganese ores only carbonateous ones would be available so, we considered two variants for silicomanganese smelting. In variant I it is proposed to use a mixture of carbonateous concentrates (II grade and jigging) with collective oxide concentrate in the ratio of 50:50. Variant II provides for the use of only carbonateous concentrates (II grade and jigging). Calculated chemical composition of silicomanganese and slag is given below:

Chemical composition of silicomanganese, % wt.

Variant	Mn	Si	Fe	C	P	S
I	63,31	15,37	19,10	1,80	0,40	0,02
II	67,84	16,35	13,43	1,94	0,42	0,02

Chemical composition of silicomanganese slag, % wt.

Variant	MnO	FeO	SiO_2	CaO	Al_2O_3	MgO	P_2O_5	S
I	10,99	1,38	49,65	25,95	4,91	6,34	0,06	0,72
II	8,17	0,68	37,19	40,86	3,95	7,91	0,05	1,19

Specific consumption of manganese raw materials for silicomanganese (SiMn17) production, kg/ton alloy:

Variant I (SiMn). Carbonateous concentrates (II grade and jigging) – 1341 kg; collective oxide concentrate 1341 kg;

Variant II (SiMn). Carbonateous concentrates (II grade and jigging) 3534 kg.

Medium-carbon ferromanganese. Production of this alloy requires construction of refining furnaces for the process and can be organized when hot silicomanganese is available within the melting shop. Only a carbonateous concentrate (I grade) can be used for smelting of standard medium-carbon ferromanganese. Two variants for m/c ferromanganese production are considered:

Variant I (m/c FeMn): Carbonateous concentrate (I grade) + Variant I (SiMn)

Variant II (m/c FeMn): Carbonateous concentrate (I grade) + Variant II (SiMn).

Chemical composition of m/c ferromanganese and slag is given below:

Chemical composition of medium-carbon ferromanganese, % wt.

Variant	Mn	Fe	C	Si	P	S
I	77.69	20.09	1.50	0.38	0.33	0.01
II	82.16	15.49	1.59	0.40	0.35	0.01

Chemical composition of medium-carbon ferromanganese slag, % wt.

Variant	MnO	FeO	SiO_2	CaO	Al_2O_3	MgO	P_2O_5	S
I	20.49	0.23	31.36	49.91	1.31	1.94	0.31	0.45
II	20.49	0.23	31.36	49.91	1.31	1.94	0.31	0.45

Specific consumption of manganese raw materials, kg/ton alloy:

Variant I (FeMn80C20): Carbonateous concentrate (I grade) – 1398 kg, silicomanganese Variant I (SiMn) - 830 kg;

Variant II (FeMn80C20): Carbonateous concentrate (I grade) – 1471 kg, silicomanganese Variant II (SiMn) - 830 kg.

Production of high-carbon ferromanganese (flux-free method) is possible at the **second stage** of industrial engineering in a smelting shop equipped with submerged electric arc furnaces on the basis of carbonateous concentrate (I grade). It will also be possible to produce a low-carbon ferromanganese and manganese metal using a foundry slag from high-carbon ferromanganese production (flux-free method). A scheme for ferroalloys production from manganese ores of Usinskoye deposit is shown in Fig. 4.

High-carbon ferromanganese (flux-free method). This technology provides extraction of ~60% of manganese in manganese ore into metal and ~30% into slag, which is used as low-phosphorus manganese raw material for production of foundry silicomanganese and manganese metal. Calculated chemical composition of high-carbon ferromanganese and slag is given below:

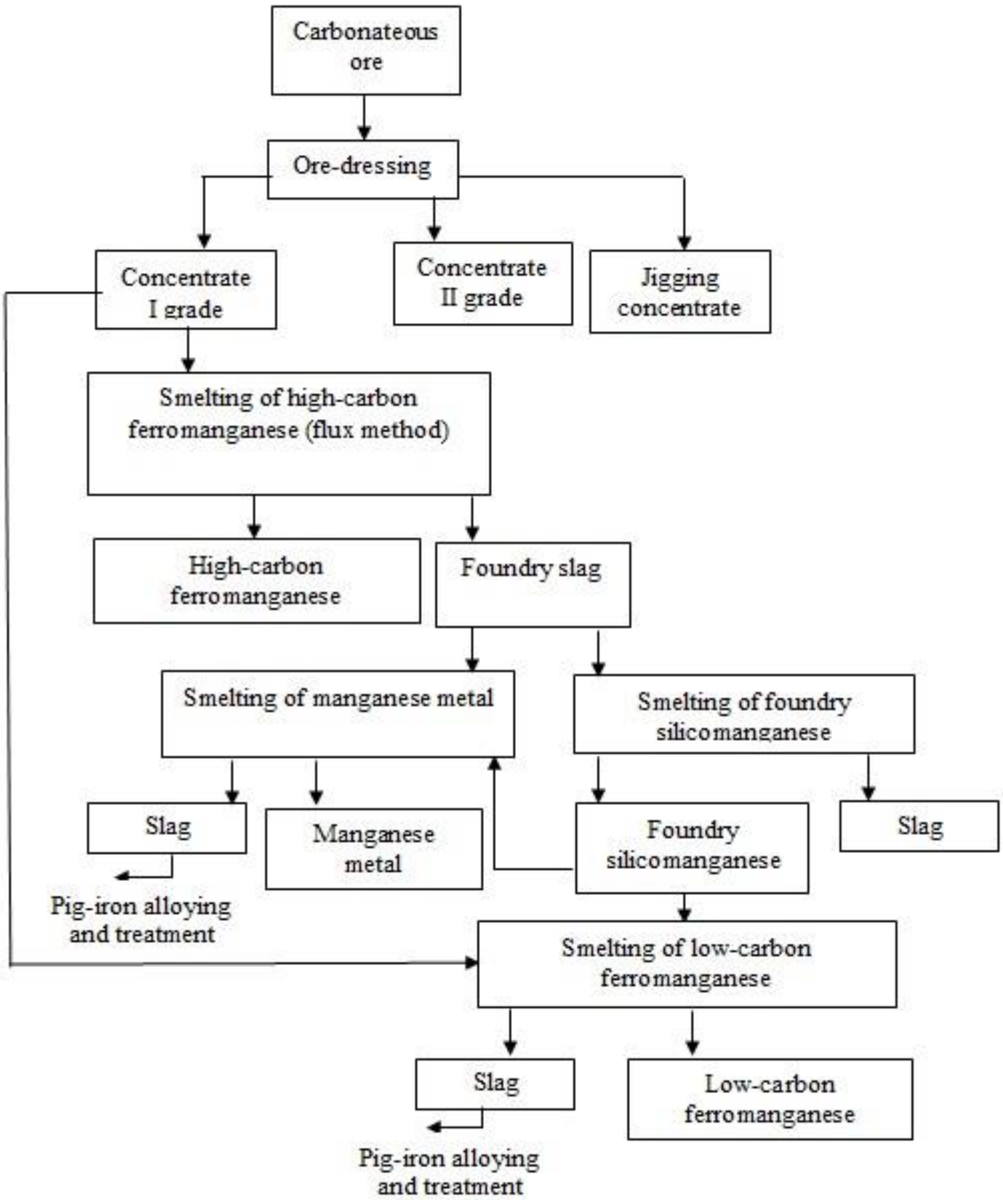

Fig. 4. Technological scheme for ferroalloys production from manganese ores of Usinskoye deposit

Chemical composition of high-carbon ferromanganese, wt. %

Mn	Fe	C	Si	P	S
78.96	12.33	6.41	1.76	0.51	0.03

Chemical composition of high-carbon ferromanganese foundry slag, wt. %

MnO	FeO	SiO_2	CaO	Al_2O_3	MgO	P_2O_5	S
40.02	0.61	28.68	21.54	4.69	5.17	0.05	1.24

Specific consumption of carbonateous concentrate (I grade) for production of high-carbon ferromanganese (FeMn78) is 3654 kg/ton. Quantity of a by-product (foundry slag: 31,0% Mn and 0,02% P) will be 1454 kg/ton. This slag can be used as a low-phosphorus manganese raw material.

Technology of silicothermal production of manganese metal consists of three stages: I – smelting of low-phosphorus manganese slag; II – foundry silicomanganese smelting from foundry slag; III – smelting of manganese metal from low-phosphorus manganese slag and foundry silicomanganese. A method for improvement of manganese extraction ratio was developed [12], where the 1st stage (smelting of low-phosphorus manganese slag) is excluded; foundry silicomanganese and manganese metal are smelted from foundry slag of high-carbon ferromanganese produced with flux-free method.

Foundry silicomanganese. The alloy is smelted from foundry slag of flux-free high-carbon ferromanganese process in SAF. Chemical composition of metal and slag is given below.

foundry silicomanganese, % wt.

Mn	Fe	C	Si	P	S
69.46	1.82	0.05	28.55	0.08	0.04

foundry silicomanganese slag, % wt.

MnO	FeO	SiO_2	CaO	Al_2O_3	MgO	P_2O_5	S
6.21	0.07	45.40	30.51	8.62	8.135	0.005	1.05

Calculated specific consumption of foundry slag for silicomanganese (SiMn25) production is 2805 kg/ton.

Manganese metal can be produced in refining furnaces from foundry slag of high-carbon ferromanganese (smelted by flux-free method) and foundry silicomanganese. Calculated chemical composition of metal and slag is given below.

Manganese metal, % wt.

Mn	Fe	C	Si	P	S
96.276	2.92	0.04	0.63	0.08	0.04

Slag, % wt.

MnO	FeO	SiO_2	CaO	Al_2O_3	MgO	P_2O_5	S
15.11	0.04	30.75	46.13	3.58	3.90	0.02	0.47

Specific consumption of materials for production of manganese metal (Mn95), kg/ton alloy: foundry slag – 3694; foundry silicomanganese – 728.

Low-carbon ferromanganese. Standard alloy can be smelted from carbonateous manganese concentrate (I grade) and a foundry silicomanganese as a reductant in refining furnaces. Calculated chemical composition of metal and slag is given below.

Low-carbon ferromanganese, % wt.

Mn	Fe	C	Si	P	S
90.86	8.19	0.04	0.62	0.27	0.02

Low-carbon ferromanganese slag, % wt.

MnO	FeO	SiO_2	CaO	Al_2O_3	MgO	P_2O_5	S
20.53	0.35	31.37	43.92	1.30	1.94	0.14	0.45

Specific consumption of materials for production of low-carbon ferromanganese (FeMn90), kg/ton alloy: carbonateous concentrate (I grade) – 2263; foundry silicomanganese – 721.

There are considerable manganese losses with slags in ferroalloy. Extraction ratio of manganese at medium- and low-carbon ferromanganese and manganese metal production processes is comparatively low (<60 – 65%) and losses with slags are at the level of 30 – 40%. Chemical composition of manganese slags (15 – 20% Mn, 0,003 – 0,005% P) allows considering them as promising manganese raw materials. Results of thermodynamic simulation of silicothermal process of manganese slags reduction by the carbon of pig-iron melts [13] showed a promising way for increase of through manganese extraction ratio. A proposed method for pig-iron alloying is protected by patent of RF [14].

CONCLUSION

A technological scheme for production of all range of manganese ferroalloys from manganese ores of Usinskoe mining deposit is proposed. The scheme is developed on the basis of sophisticated analysis of chemical composition of manganese raw materials obtained after concentration of base lump ores. It was shown that production of standard manganese ferroalloys from domestic ores can be organized without involvement of rich low-phosphorus imported manganese ores into smelting process.

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