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Innovative Technologies in Ferrosiliconmanganese Production

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Abstract
The introduction of innovative technologies at the ZestafoniFerroalloy Plant: the use of perlite as a substitute for quartzite, the melting of steel scrap in the liquid alloy and the production of furnace hole sealing paste significantly improved the technical, qualitative and quantitative indicators of the products, which led to significant economic benefits and is perceived as a new word in the ferroalloy industry.

Keywords:*silicomanganese, quartzite, perlite, scrap, paste, exothermic, heatcapacity.*

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I. Introduction

Ferrosilicomanganese is considered one of the elite metallurgical products, even because its production requires at least 5 times more electricity than the production of electrical steel. Ferrosilicomanganese metallurgy is distinguished by a variety of raw materials (manganese ores, concentrates, quartzites, restorative agents - coke and coal, limestone, lime, etc.) and other auxiliary technological materials (refractory brick, electrode, coal block, hole paste, etc.).

The quality and price of these materials determine the prime cost of the final product - ferroalloy. Unfortunately, the quality of raw materials brought to the market is constantly deteriorating and the price is permanently increasing, which forces entrepreneurs in this field to look for new and cheaper alternative technologies. From this point of view, the metallurgists of ZestafoniFerroalloy Plant are no exception.

Use of perlite as a replacement raw material for quartzite

Since 2021, the Zestafoni Ferroalloy Plant has begun replacing expensive Turkish quartzite with relatively cheap local perlite, produced in the municipality of Tsalka, in the production of ferrosilicomanganese, the chemical composition of which is given in Table 1.

Chemical composition of perlite %
Table 1.

SiO_2	Al_2O_3	Fe	CaO	H_2O	Na_2O+K_2O
70.10	12.00	0.60	0.70	12.60	7.20

The work serves two purposes:

- to reduce the cost of manufactured goods (SiMn) by partially replacing expensive imported quartzite with cheap perlite, switching to pure SiO_2;
- using perlite to increase the fluidity of silico-manganese slag and, as a result, to reduce the losses of finished products in the accompanying slag.

The content of silica (SiO_2) in imported quartzite reaches 97%. As can be seen from Table 1, its content in perlite is much lower (SiO_2-70%). Nevertheless, the inclusion of perlite in a certain ratio with imported quartzite in the charge has a positive effect on the overall economic indicators and the prime cost of the products. As a result, partial replacement of imported quartzite with perlite brought significant economic benefits to the plant.

Immersion of steel scrap in liquidmelt

In the production of manganese ferroalloys, various types of iron-containing ores were initially used as iron-containing raw materials, and later, the waste of the metalworking industry in the form of steel slag and scrap. Thesematerialsweredirectlysuppliedtothefurnaceasthereagentsofthecharge.

Figure 1.Placementofsteelscrapintheladle

Since 2017, scrap steel that is unsuitable for production has been used at the plant as an iron-containing material to produce SiMn. Scrap in the amount of 100-600 kg, taking into account the ordered chemical composition of the commercial product, is placed in the ladle with a volume of 2.13 m^3 before each release (Fig. 1). After pouring the molten products from the furnace into the ladle, the scrap smelts.

For more visibility, in Table 2, we present the chemical composition of the alloy (in mass %) before and after smelting of the scrap steel:

Table 2.

Alloy	Mn	Si	P	C	Fe
Before meltingof the scrap	74,0	18,4	0,34	1,8	4,9
After melting	67.5	16.6	0.31	1.6	13.9

The melting process in the first approximation can be considered as a heat exchange task between two inert bodies in the case when one body is solid (scrap) and the other is liquid (silicomanganese). Of course, the final, complete model of the process must take into account the enthalpy of formation of silicides, the thermal effects caused by mutual solubility of the reactants, and other thermochemical aspects.

At the beginning, let's consider the process of heating of steel scrap, as an inert body, at the expense of cooling of the molten silicon manganese until the temperatures equalize. The heat balance of the process can be written in the form of the following algorithm:

$$\boldsymbol{m_{SiMn}C_P^{SiMn}(T_1 - T) + m_{Fe}C_P^{Fe}\,(T - T_0) + Q = 0}, \quad (1)$$

Where: $m_{SiMn}$and $m_{Fe}$are the masses of the reactants (silicomanganese and iron) participating in the process,C_P^{SiMn} და C_P^{Fe} – their specific isobaric heat capacities, T1 is the temperature of the molten silicomanganese at the moment of release from the furnace, T0 is the initial temperature of the scrap, and T is the final temperature of the process.Q – are heat losses (heat dispersion in the environment, heating of the ladle. It is clear that these losses do not change from casting to casting, are regular in nature and can be taken out of consideration as a constant

The whole process, i.e. the process of equalizing the temperature field in the system, depends on two variables (parameters): the amount of iron scrap and its initial temperature. The ordered composition of iron in the commercial product determines the weight of the scrap, which under the conditions of the ZestafoniPlant (volume of ladle 2.15 m^3, mass of the molten silicon-manganese 8200 kg) ranges from 100 to 800 kg;

The lower limit of the casting temperature on the casting machine is determined by the liquidus regions indicated on the state diagrams of the ferro-silico-manganese system, and prohibits us from allowing the temperature of the ladle to be fallen below this temperature limit during the casting process.

The thermochemical parameters of the reagents involved in the process are as follows:

Atomic heat capacity of molten manganese – 46.2 J/mol ·K from the melting temperature (T_L) in the temperature range of 1873^{0}K [3];

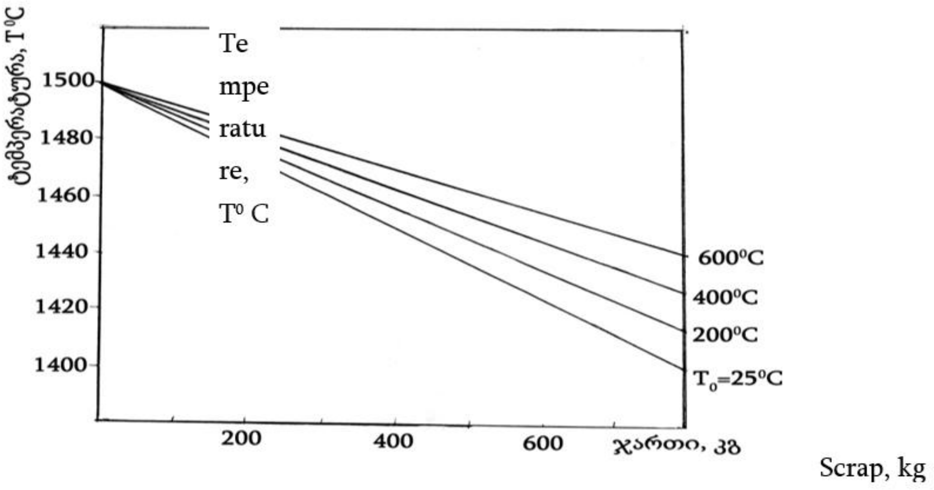
Atomic heat capacity of molten silicon – 25.7 J/mol ·K from the melting temperature (T_L) in the temperature range of 1873^{0}K [3];

According to the Neumann Kopp'sadditivity rule, the molar heat capacity of molten silicomanganese is determined to be 35.95 J/mol·K and accordingly, the specific heat capacity is $35.95/0.5M_{Mn}+0.5M_{Si}$ = 860 J/kg·K, (M – molecular weight), the value of which was used by us during the calculations. The average specific heat capacity of iron is taken as $C_P^{Fe} = 641$J/kg·K.

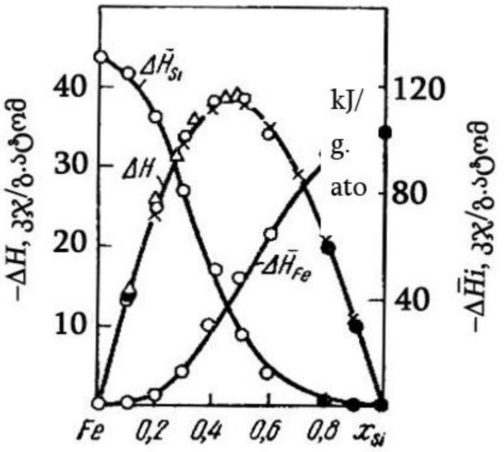
Taking into account these characteristics, under conditions of the fixed initial temperature of the scrap (T_0=const), the total equilibrium temperature of the system (T) calculated by the formula (1) decreases linearly with the increase of the mass of the scrap. This result can be presented in Table 3 form or graphically.

Table 3.
The final equilibrium temperature of the smelting processT^0 C

Scrap, kg	**Equilibrium temperature T^0 C**			
	T_0=25^{0}C	T_0=200^{0}C	T_0=400^{0}C	T_0=600^{0}C
200	1475	1479	1482	1485
400	1450	1456	1463	1470
600	1425	1435	1445	1456
800	1400	1414	1427	1441



It should be noted here that iron and silicon interact strongly and form several silicides (Fe_3Si, Fe_5Si_3, FeSi, $FeSi_2$) mixing, of which FeSi is congruent [1]. This fact is clearly reflected in the sign and value of the mixing heat, in particular, it has been established [2] that the value of the first dissolution heat of iron insilicon exceeds 100 kJ/g.atom, and the integral value of the mixing heat is DH=-38kJ/g.atom (Fig. 2).This indicates that the mixing of the molten components is a strongly exothermic process, with the release of heat [3] and is likely to contribute to the fusion process of the scrap metal with the molten silicon.



kJ/
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Fig.2. The partial (ΔH_i) and integral (ΔH) values of the mixing heat of iron and silicon according to [2]

This technology has provided us with significant economic benefits. This means that we finally got a surplus of finished products, on which coke, coal and electricity were not spent, it was obtained only by melting of iron scrap in the ladle.

It should be noted that this technology, in addition to eliminating the cost of electricity required for scrap melting and providing the factory with significant economic benefits, also improved technical indicators: it reduced the phosphorus content in the commercial products, and increased the physical-mechanical strength of the products. As a result, the share of fractional products in the crushing process increased significantly and the amount of fines breeze (0-10 mm) decreased accordingly.

Self-made paste for closing the furnacedischarginghole

The process of opening and closing of the discharging hole of the metallurgical smelting vessel has always been considered one of the most responsible operations in the metallurgical industry. Until the twentieth century, this process was done by hand and required great skill from the performer, who also had to prepare a paste-like mass on a base of refractory clay to cover the hole.

In the 20th century, the mechanizationprocess of the opening and closing the hole began, which also required the industrial production of hole-closure paste. At the Zestafoni Ferroalloy Plant, a machine for opening and closing the furnace hole was first installed in 2014 on furnace # 2 of workshop # 1 of the plant, at which time the use of the paste started. Currently, twofurnaces (# 2, # 6) of workshop # 1and four furnaces (# 22, # 23, # 24, # 26) of workshop #4 are equipped with such machines. Accordingly, the cost of the holeclosing paste has also increased.

The hole closing paste in the factory was mainly imported from abroad (China), it took more than two months to produce and transport the paste, and its service life in operation was 6 months, which caused some inconvenience in the production process and often caused failures in the supply of paste, especially during the period of the global pandemic.Deficiency of hole closing paste resulted in damage to the walls of the outlet hole. Taking into account all the above, in August 2021, trial works were started using the secondary resources available in the factory (coke breeze, electrode mass, clay soil, sand, tar pitch) for the on-site production of the hole closing mass.

Currently, appropriate technological recipes have been developed and the metallurgical laboratory of the factory is equipped with appropriate equipment: a drying chamber, a mill, a dry mixer, a runner, and a mixer made in China, a sieve with two output belts, an electric balance and others.

Fig. 3. A kneading apparatus (Shimpo NVS-07) for making paste

By producing our own paste for the furnace hole, the quality of the commercial goods has been significantly improved.

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