Parameters of the Lower-Belt Lining of Ore-Smelting Electric Furnace Shafts for Melting High-Silicon Ferroalloys

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Abstract—The graphite belt (GB) of the bottom is an important element in the design of the shafts of ore-smelting electric furnaces, since it prevents an oxide lining from contact with liquid ferrosilicium. The problem of choosing the GB height as a function of the furnace power and the silicon content in an alloy is formulated and solved.

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An ore-smelting electric furnace is a high-temperature chemical retort in the working space of which initial charge components (ores, carbon reducers, fluxes, etc.) transform into end products (alloys, slags, gas) [1].

By analogy with a blast furnace, an electric furnace for carbothermic reduction of metals is called a shaft furnace and the working space (bath) is called a shaft.

To provide relative symmetry of near-electrode electric and heat fields, the furnaces predominantly have rounded shapes of a steel body and a lined shaft. Electrodes are arranged at the vertices of an equilateral triangle inscribed with respect to the vertical axis of symmetry of the shaft.

The shaft walls and the lower layers of the bottom are lined by oxide refractories (corundum, magnesite, chamotte). The upper layer of the bottom in contact with a melt is made of graphite blocks. As compared to other refractories, they have a high heat resistance, a low thermal expansion coefficient, and a low chemical activity with respect to silicon and iron, manganese, and chromium silicides. The lower belt of the shaft lining is also made of graphite blocks sealed by an electrode mass in joints.

The main purpose of the graphite belt (GB) is to prevent the oxide part of the lining from contacting a molten high-silicon metal overheated to 1600–1700°C. The belt height from the upper level of the bottom is a priori taken to be \((0.5–1.0)d_e\), where \(d_e\) is the electrode diameter. Technical literature has no any reasonable justification of this value, while it significantly affects the useful resistance of the electric load circuit.

These considerations can easily be understood if we analyze the equivalent circuit of the electric circuit in the furnace working space (Fig. 1). The larger the GB height, the higher the degree of shunting of charge resistance \(R_{ch}\). The graphite bottom and belt form grounded “0” of the bath. The passage of part of the current through a side wire \(R_{gb}\) decreases the electric current, the power released across the charge resistance, and the contour resistance. Therefore, GB cannot be excluded.

The allowable GB height can be calculated using the well-known data on the density of iron–silicon...
melts δ (t/m³) [2] and the specific consumption of electric power W (MWh/gt) in the production of ferrosilicium containing 25–98% silicon [3].

The dependences of δ and W on the fraction of silicon in an alloy are shown in Fig. 2.

Obviously, the GB height should be larger (by 5–10%) than the calculated melt layer thickness accumulated in a heat cycle.

The calculations were carried out using two furnaces with a power of 10.5 and 16.5 MVA and an electrode diameter of 0.9 and 1.2 m, respectively. The power coefficients are 0.85 and 0.82, respectively. The heat cycle time from tapping to tapping is 2 h. The main assumption used for the calculation is that all three electrodes are loaded identically, one-third of the furnace active power.

The alloy mass accumulated per heat cycle in the zone of action of one electrode was calculated by the formula

\[
g = (S \cos \varphi 2)/(3W),
\]

where \( g \) is the alloy mass (t), \( S \) is the total furnace power (MVA), \( W \) is the specific electric power consumption (MWh/gt), 2 is the cycle time (h), and 3 is the number of electrodes.

The calculation results are shown in Fig. 3. It is natural that, at the same electric energy extraction, the accumulated alloy mass decreases with increasing silicon content.

The capacity of the 16.5-MVA furnace is higher than that of the 10.5-MVA furnace over the entire alloy composition range.

The alloy volumes produced in a 2-h cycle were calculated by the formula

\[
V = g/\delta,
\]

where \( V \) is the alloy volume (m³) and \( \delta \) is the alloy density in the liquid state (t/m³).

The calculation results are shown in Fig. 4. The alloy volume in the 16.5-MVA furnace is substantially larger than in the 10.5-MVA furnace.

The actual geometry of the volume accommodating a certain alloy cannot be determined. Therefore, we conventionally assumed that the entire alloy mass is concentrated in a cylinder with a diameter equal to the electrode diameter. Then, we can calculate the conventional layer thickness,

\[
h = V/(0.785d_e^2),
\]

where \( d_e \) is the electrode diameter (m) and \( h \) is the metal height (m).

Figure 5 shows the change in the conventional alloy height as a function of the silicon content from 25 to 98% silicon. It is seen that the minimum accumulated alloy volume and height are located at 75% silicon. When the silicon content increases to 98%, these parameters increase.